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A RATIONAL SYSTEM FOR ASSIGNING RESEARCH AND DEVELOPMENT PRIORITIES AT ADVANCED WASTE TREATMENT LABORATORY, CINCINNATI, OHIO

Federal Water Quality Administration
Cincinnati, Ohio

September 1970

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A RATIONAL SYSTEM FOR ASSIGNING RESEARCH AND DEVELOPMENT PRIORITIES

AT

ADVANCED WASTE TREATMENT LABORATORY, CINCINNATI, OHIO

By

Treatment Optimization Research Program

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Advanced Waste Treatment Branch, Division of Research
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70

INTRODUCTION 1

METHODS AND CONCEPTS FOR SETTING PRIORITIES 2

SCOPE OF THE POLLUTION CONTROL AND REUSE PROBLEM 8

CURRENT RESEARCH AND DEVELOPMENT NEEDS 13

STAFFING AND EXPENDITURES 18

INFLUENCE COEFFICIENTS 22

WHAT NEEDS TO BE DONE 31

REFERENCES 33

APPENDICES . . . . . .

INTRODUCTION

The importance of spending monetary and manpower resources wisely in the fight to conserve the Nation's water resources was emphasized recently in the first annual report of President Nixon's council on environmental quality in the following words:

> "Choices will have to be made on which problems have first claim on these resources. Four main criteria should determine this priority:
>
> . The intrinsic importance of the problems--the harm caused by failing to solve them.
>
> . The rate at which the problems are going to increase in magnitude and intensity over the next few years
>
> . The irreversibility of the damage if immediate action is not taken
>
> . The measure of the benefits of society compared to the cost of taking action."

All government agencies involved in conservation have a clear responsibility to match effort expended with the two key factors mentioned in the quote. These two factors are first, the importance of the problem to the Nation and second, the time frame for finding the solution and correcting the pollution problem.

Consideration of priorities is of such importance and involves so much interaction with other governmental and non-governmental groups, and even the public at large, that it should be pursued as a continuing activity rather than being treated as a decision made at one time and at one place. Actually, rational decisions can often not be made without a considerable amount of staff support.

The following pages represent a first attempt to supply this staff work for the AWT R&D Program in Cincinnati. Since most of the work in

Cincinnati is directed toward development of processes for wastewater treatment (PPBS 1700), the following discussion will be limited to this area of activity. The priority setting considerations presented will be wholly objective. Organizational, political, and personality constraints will be excluded. It will be assumed that consideration of these more subjective factors will follow the objective analysis and some reordering of priorities will be required.

It will be shown that existing theory for priority setting is not foolproof and much depends on accurate estimating. The ideas of cost-benefit analysis and planning are useful and if used properly can bring the problem into clearer focus and lead to a rational decision making process.

In any kind of analysis it is proper to begin with a gross approach and to refine the analysis only if the gross approach will not serve as an adequate basis for decision making. This policy will be followed throughout the following discussion.

In attempting to develop an objective method for setting R&D priorities it is necessary to have in mind certain cost-benefit concepts and these will be developed in a non-mathematical way. Mathematical details will be relegated to appendices.

METHODS AND CONCEPTS FOR SETTING PRIORITIES

The concept of profitability which is used extensively in the business world to make decisions on the allocation of corporate funds and man-power can also be used to set priorities in government sponsored research

and development. The theory of cost-benefit analysis has been worked out in great detail and is presented in various texts on cost engineering and water resources management. For example, see References 1-3.

Two basic concepts underlie cost-benefit analysis. The first is the time value of money; a sum of money today is worth more than a promise to pay the same amount at some future date. The second, which relates more directly to business investment, asserts that any investment which yields a return less than the current interest rate is not justified.

As with all theoretical approaches the difficulty in applying the theory is associated with estimating the variables as they exist in the real world. To apply the theory we first need well defined research needs. The level of effort required to satisfy the need must be estimated and the anticipated benefit in terms of improved processes efficiency or reduced cost must also be estimated.

The expenditure for research and development might be in the form of lump sum payments or in terms of a yearly expenditure over a specified period of time. Since the value of money depends on the time at which it is spent, we must convert all expenditures for R&D to a present value. This is done, as described in Appendix I, by dividing each expenditure by a factor which increases with time. The factor is $(1+i)^n$ where i is the interest or yield rate for municipal bonds and n is the number of years from the present time when the money is expended. If all expenditures are divided by the appropriate factor and summed, the result is the present value cost of the research project.

In a similar way the benefits realized in the form of a treatment cost saving or an improvement in process efficiency must be converted to a present value. The net value of the R&D project is then taken as the present value of the benefits minus the present value of the R&D expenditures.

If two R&D projects are proposed and money is available to fund only one of the two, the project with the larger net value should be funded. If a group of projects must be selected for funding in a particular fiscal year, the projects must first be ranked according to net value and the highest ranked projects selected until the available funds are exhausted. This procedure will, theoretically, maximize the effectiveness of the R&D program within the funding constraint. Clearly, estimating the net value of each R&D project presents an obstacle in both staff work required and accuracy. If the evaluations could be made with some accuracy, however, the procedure for making the choice is clear.

An important consideration is how to evaluate an improvement in process efficiency when the treatment cost remains fixed. One way of approaching this problem has been to place a value on the improvement in the condition of the receiving stream resulting from the improvement in treatment efficiency. This approach has been used by socially oriented resource planners and the problem deteriorates into attempting to place a value on a day of fishing or a boat ride. This procedure only brings more uncertainty into the problem. A more logical and easier to quantify method is to evaluate the improvement in efficiency in terms of the cost of a process modification or additional process which would be required to effect the same reduction in pollutional load to the receiving stream.

For example, assume that by means of installing in the final clarifier a sludge blanket detector, which regulates the volume of the return stream to the aerator, the suspended solids discharged from the final clarifier could be reduced from 20 mg/1 to 10 mg/1. The cost saving should be taken as the incremental cost of a process modification which would result in the same reduction in suspended solids. The next question is which process modification? For example, the final clarifier can be made larger or a microscreen or sand filter might be installed downstream of the final clarifier. Clearly, the least cost alternative to achieve the improvement must be used.

Since this kind of information will be needed to evaluate the benefit of any improvement in process cost or removal efficiency, we need accepted standards for the cost of treatment for removal of each water contaminant which reflect the current state-of-the-art. These kind of relationships have been developed as a guide for charging industrial firms who discharge wastewater into public sewers. An example of such a relationship which was developed at AWTRL in Cincinnati for the conventional activated sludge plant is presented below. In this example effluent quality was held fixed, and only small changes were considered.

$$F_t = .174\ F_1 + .235\ F_2 + .206\ F_3 + .121\ F_4$$

where

F_t = % increase in total treatment cost

F_1 = % increase in raw dissolved BOD

F_2 = % increase in raw solid BOD

F_3 = % increase in raw inert particulate

F_4 = % increase in volume flow

Another point which needs clarification is the distinction between a clear-cut improvement in process efficiency or a cost reduction and a gross lack of knowledge about the capabilities and cost of a process. For example, at the present time the height of a transfer unit for ammonia stripping towers is known only within a factor of three. This means that if 90% removal of ammonia nitrogen is required, we cannot specify the height of the tower except within a factor of three. How important is it to know the height of the tower more accurately? Without this information the designer will build the tower either too large or too small. If the tower is made too large, the cost penalty can be taken as the difference between the cost of the larger tower and the cost of the required tower. Since the penalty for discharging more than the recommended amount of pollutants to the stream has been traditionally low, the error will probably result in a tower which is too small. These arguments are highly theoretical because if any appreciable number of towers are built, the correct value for the height of a transfer unit will be discovered and the error corrected.

It would appear, therefore, that great uncertainities in design parameters should not have a proportionally large effect on the priority assigned to the project.

Other complications also present themselves. For example, if a three year project is needed to solve a problem and one year has been completed, how do we decide to continue or terminate the project? An estimate of net value has presumably been made when the three year project was initiated. Based on the result of the first years work this

estimate should be updated and if the priority is still high, the second year should be funded. Otherwise the project should be terminated. A running list of priorities should be maintained and as new projects are evaluated they should be inserted into the list with the proper rank.

Another complication is how to treat activities which are in support of the direct effort to improve process efficiency or reduce process cost. For example, development of new analytical methods for measurement of pollutants in raw or treated wastewater. Development of mathematical or statistical methods for analysis of data and for decision making is another example. In general, the kinds of R&D activity can be roughly classified by the following three mutually exclusive categories.

A. Identify, evaluate, and quantify technological needs for pollution control and reuse of wastewater.

B. By means of research, development, and demonstration encourage development of needed technology for measurement, rational design procedures for new and existing processes, operation and staffing policies, cost estimation, water resource management, etc., to facilitate the solution of pollution control and wastewater reuse problems in the most cost-effective way.

C. By interacting with municipalities, engineering firms, universities, and governmental agencies bring the new technology into general practice by assisting in the solution of pollution control and wastewater reuse problems.

A minimum amount of activity under category A is necessary before we can even begin to evaluate priorities. Activity under category C is required if the results of the R&D Program are ever to be put into practice. A policy decision is necessary to proportion the effort among these three categories of work. A proposed division might be 10% for category A, 70% for category B, and 20% for category C. It is difficult to identify all effort according to these categories but it is important to realize that some minimum amount of effort must be made in all three areas if a viable research program is to be maintained.

SCOPE OF THE POLLUTION CONTROL AND REUSE PROBLEM

The magnitude of expenditure for improving wastewater treatment can be better appreciated when we look at it as a part of the national goal to control pollution from all sources. U.S. News and World Report recently published estimates of spending required to overcome the backlog of pollution control needs. These dollar amounts to be spent over the next five years are shown in Table I. The ten billion dollars cited for municipal wastewater treatment is divided about equally between the cost of constructing the treatment plant and the cost of laying interceptor and outfall sewers. Notice that the expenditure needed for municipal sewers is about three times the needed expenditure for treatment plants equipped with interceptors and outfalls. The cost of building new municipal plants is, therefore about 12.5% of new municipal facilities for water pollution control. Using information from Reference 4 these anticipated needs for municipal wastewater treatment have been projected through the year 2000. These estimates are shown in Figure 1.

TABLE I

ESTIMATES OF POLLUTION-CONTROL COSTS OVER THE NEXT FIVE YEARS (1971-1975)

		Dollars
CLEANING UP THE WATER		
Sewer systems, new and improved		30 billion
Municipal waste-treatment plants		10 billion
Controlling sediment		6.8 billion
Industrial waste-treatment equipment		4.4 billion
Cooling power-plant water		2.1 billion
Waste treatment on ships		0.7 billion
	TOTAL	54.0 billion
CLEANING UP THE AIR		
Auto-pollution control		5.9 billion
Controlling smoke, fumes, dust from industry		5.3 billion
Government research, other programs		1.6 billion
Controlling incinerators, open burning		0.3 billion
	TOTAL	13.1 billion
DISPOSING OF SOLID WASTES		
Updating collection systems		2.8 billion
Eliminating open dumps		1.2 billion
Increasing incinerator capacity		0.2 billion
	TOTAL	4.2 billion
	TOTAL COST	71.3 billion

Source: Estimates by U.S. News and World Report Economic Unit, based on data from U.S. Depts. of the Interior and Health, Education and Welfare; Bureau of the Budget, and Industry sources

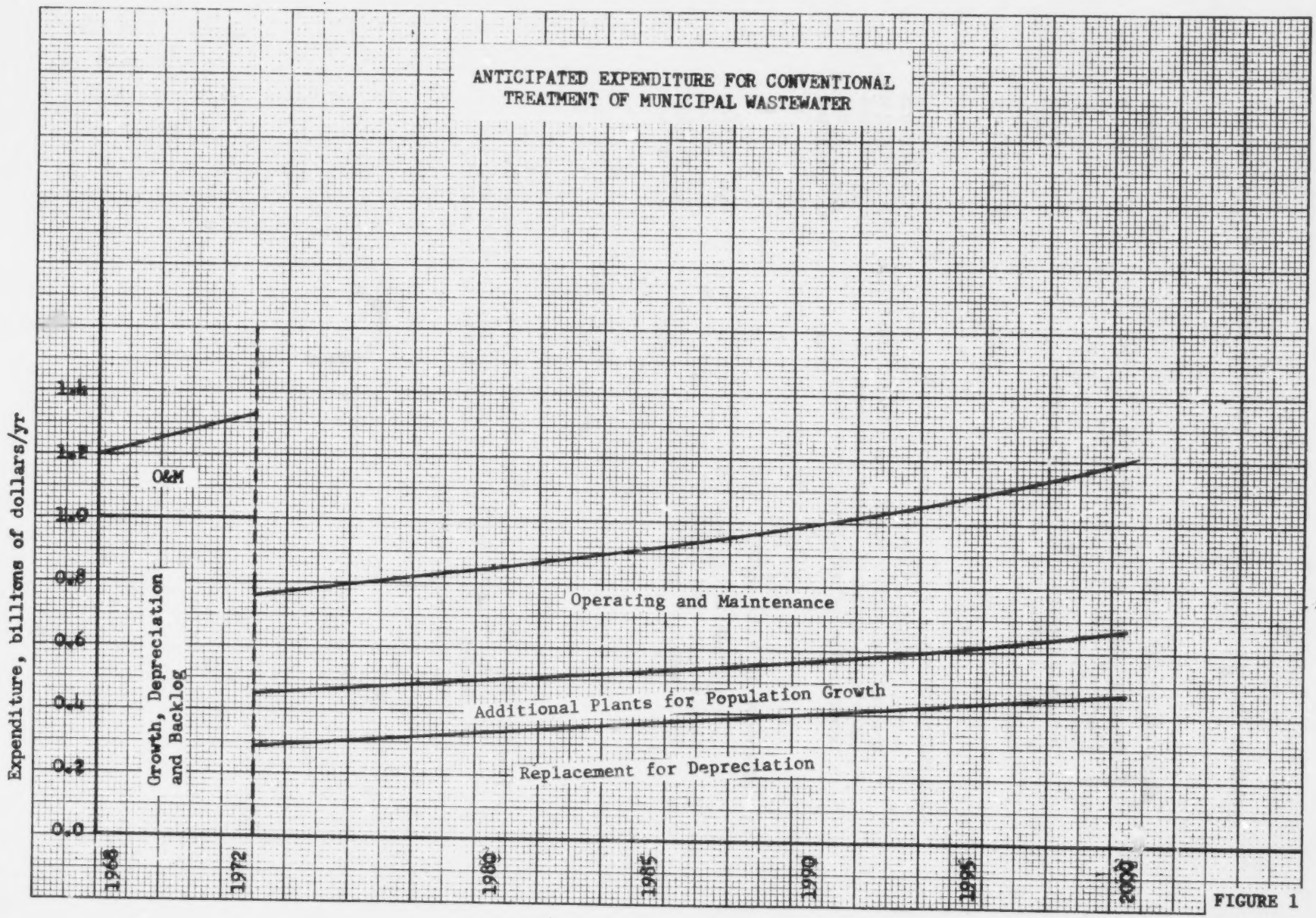

ANTICIPATED EXPENDITURE FOR CONVENTIONAL TREATMENT OF MUNICIPAL WASTEWATER
Expenditure, billions of dollars/yr
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
O&M
Growth, Depreciation and Backlog
Operating and Maintenance
Additional Plants for Population Growth
Replacement for Depreciation
1968
1972
1980
1985
1990
1995
2000

FIGURE 1

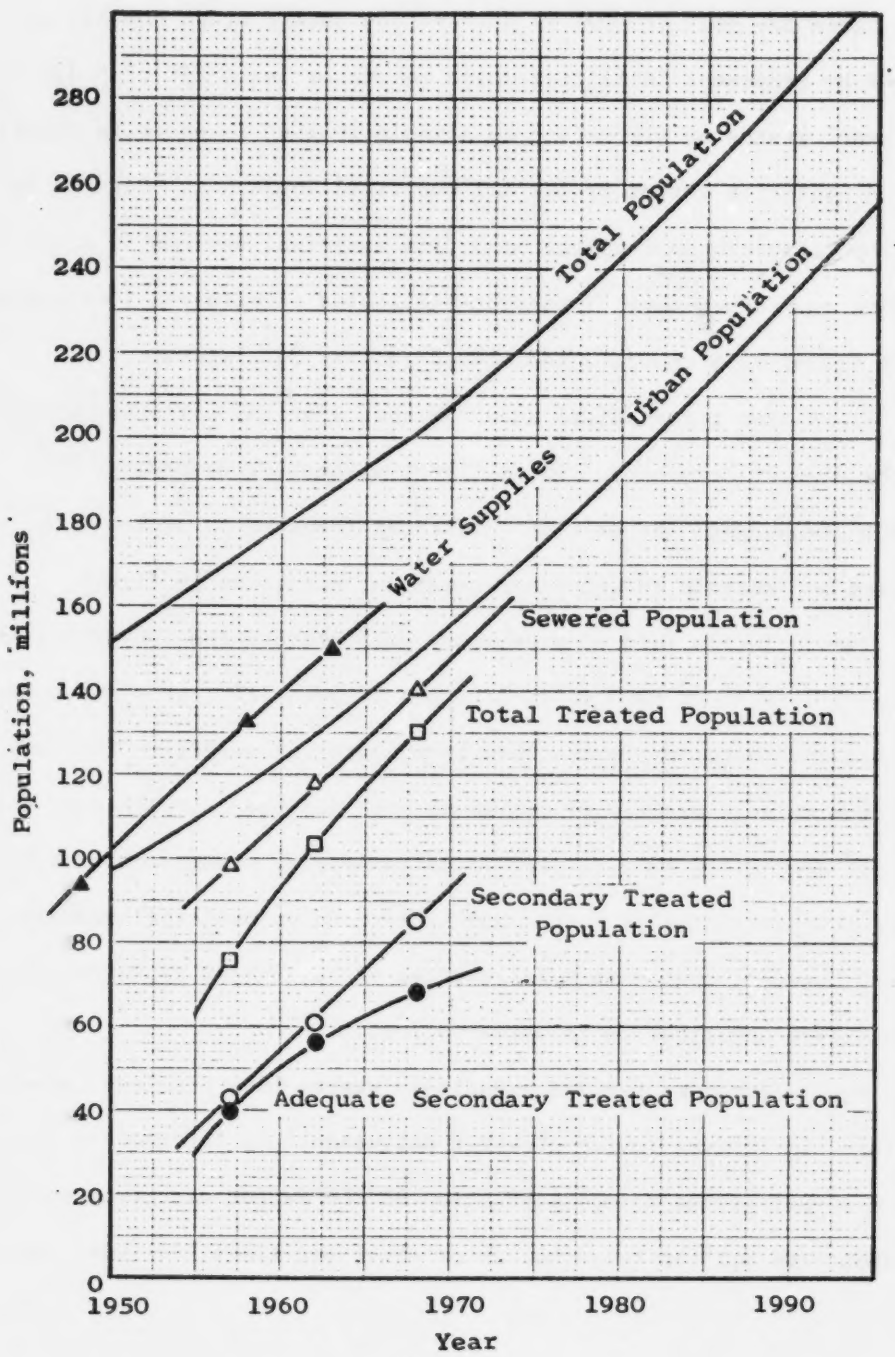
Since the goal of FWQA is to have the entire urban population served by treatment facilities which remove at least 85% of 5-day BOD, the treatment status of the Nation as a whole in 1968 is shown in Figure 2.

A pollution inventory for all municipal sources is shown in Table II. The total raw pollutional load from municipal sources is about 25 million pounds per day. Treatment facilities existing in 1968 removed about 43% of this amount. The stated goal is 85% removal.

It is also important to know the source of the pollution according to the size of community. These distributions for wastewater flow, pounds of BOD discharged, and capital investment required to overcome the treatment backlog and upgrade to secondary treatment are shown in Figures 3, 4, and 5.

The pollution load of wastewater generated by the industrial sector (Table III) is about 60.3 million pounds of 5-day BOD, or about three times the raw wastewater pollution load from municipal sources. The extent to which this is treated is not known with any precision because Congress has not authorized FWQA to perform an industrial wastewater treatment plant inventory similar to the inventory made on municipal sources. It is clear, however, that industrial sources of wastewater represent a potentially significant contribution to water pollution.

Agricultural wastes and especially wastes from feedlots represent another significant source of water pollution. In Reference 5 the total waste output of the animal population of the Nation was given as equivalent to about two billion human beings or about ten times the total raw municipal load.



STATUS OF MUNICIPAL WASTEWATER TREATMENT FACILITIES IN THE UNITED STATES

FIGURE 2

TABLE II

INVENTORY OF ORGANIC POLLUTION IN STREAMS

FROM MUNICIPAL SOURCES

1968

UNTREATED WASTEWATER		
Unsewered (9 million population)	1.503*	
Sewered but Untreated (9.58 million population)	1.617	
Minor Treatment (1.36 million population)	0.227	
TOTAL	3.247	
TREATED WASTEWATER		
Primary (38% removal)		3.825
Activated Sludge and Extended Aeration (88% removal)		.827
Trickling Filter (82% removal)		.890
Intermediate Treatment (50% removal)		.489
Unknown, Ponds, Application to Land and Intermittent Sand Filters (50% removal)		1.230
Tertiary Treatment (95% removal)		.0027
TOTAL		7.264
TOTAL UNTREATED AND TREATED WASTEWATER	10.611	
TOTAL RAW WASTEWATER PRODUCED (149 million population)	24.88	
OVERALL PERCENT REMOVAL	42.6%	

*Millions of pounds of 5-day BOD/day

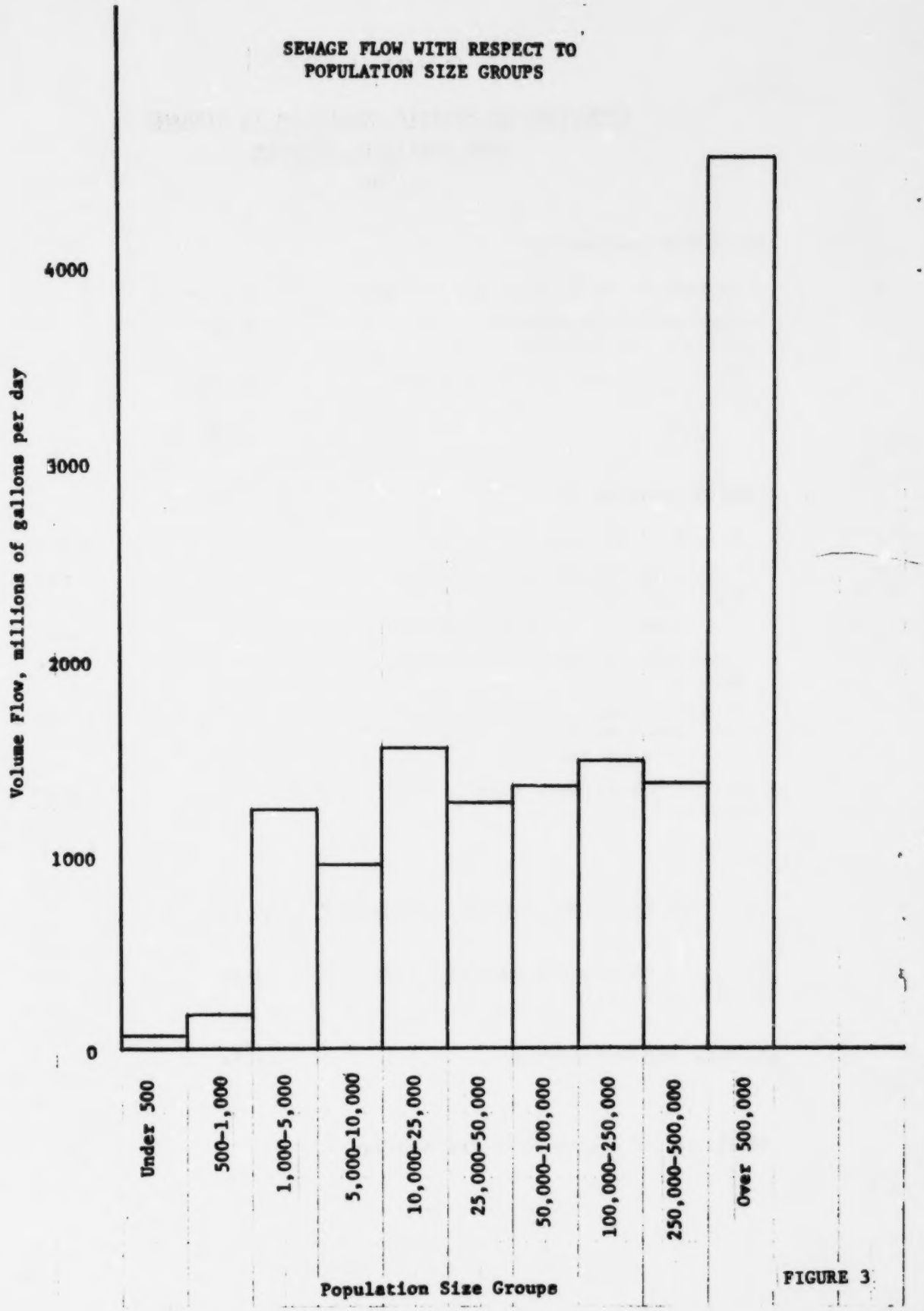

SEWAGE FLOW WITH RESPECT TO
POPULATION SIZE GROUPS
Volume Flow, millions of gallons per day
4000
3000
2000
1000
0
Under 500
500-1,000
1,000-5,000
5,000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000-250,000
250,000-500,000
Over 500,000
Population Size Groups

FIGURE 3

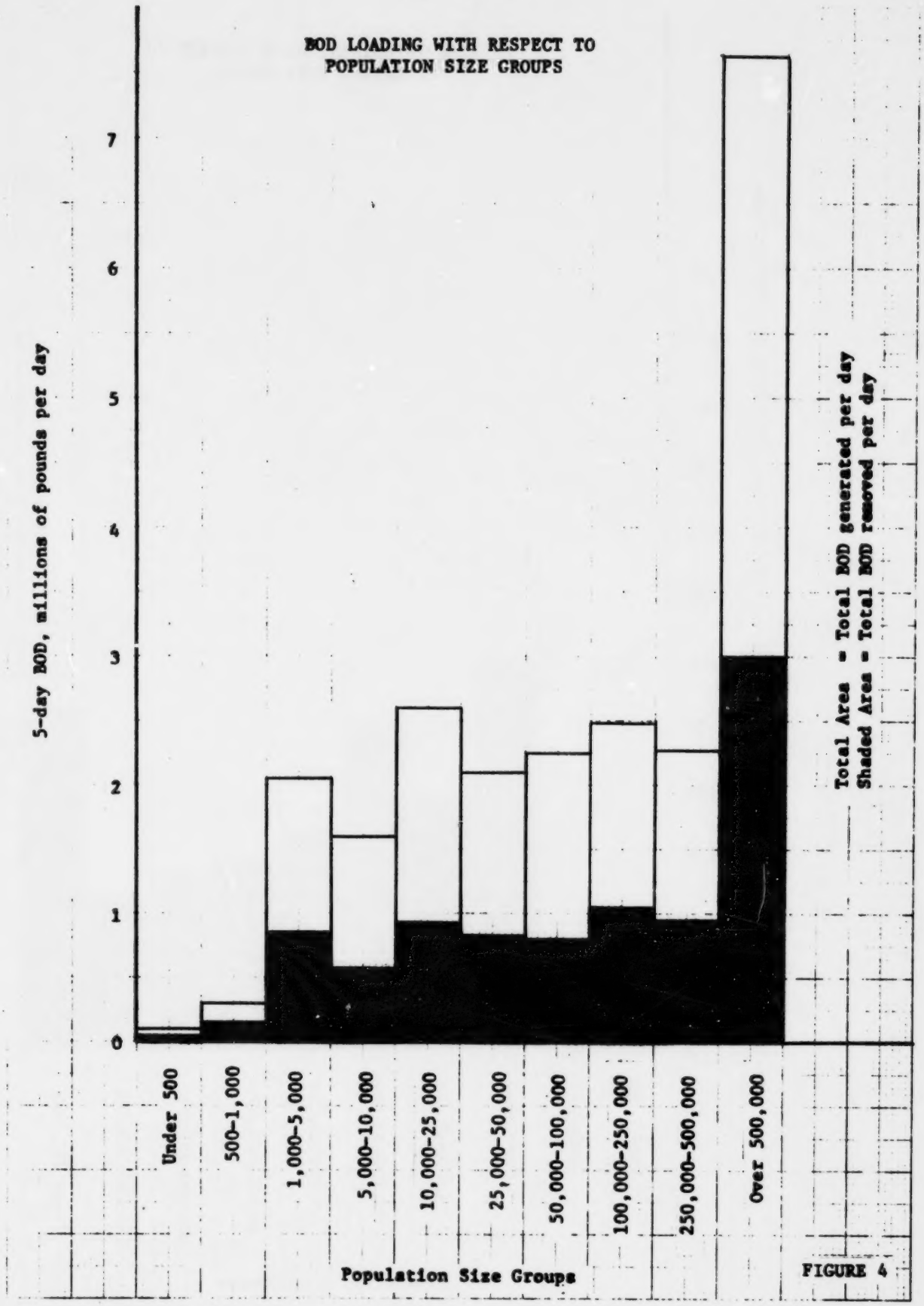

BOD LOADING WITH RESPECT TO
POPULATION SIZE GROUPS
5-day BOD, millions of pounds per day
0
1
2
3
4
5
6
7
Under 500
500-1,000
1,000-5,000
5,000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000-250,000
250,000-500,000
Over 500,000
Population Size Groups
Total Area = Total BOD generated per day
Shaded Area = Total BOD removed per day

FIGURE 4

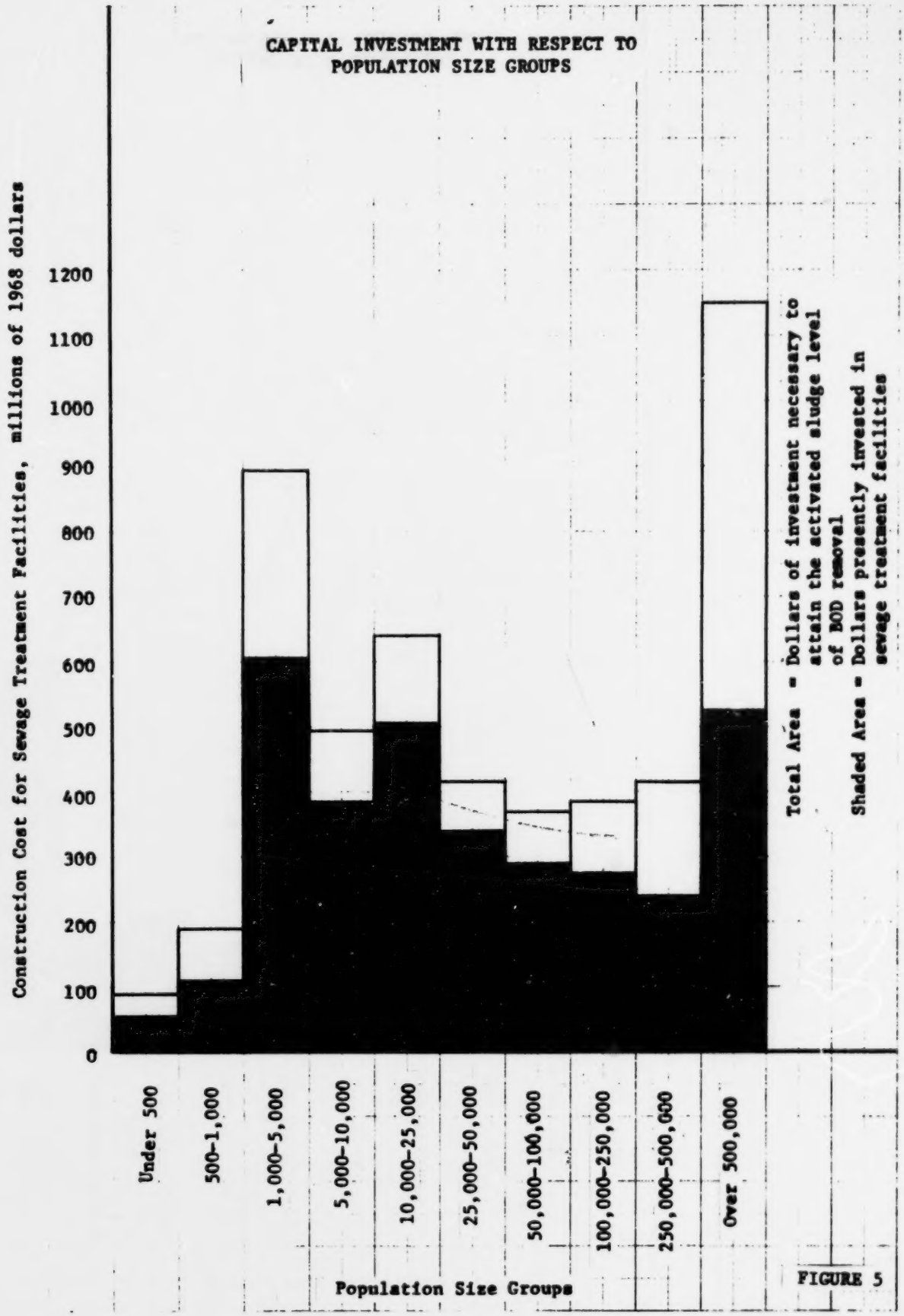

CAPITAL INVESTMENT WITH RESPECT TO
POPULATION SIZE GROUPS
Construction Cost for Sewage Treatment Facilities, millions of 1968 dollars
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Under 500
500-1,000
1,000-5,000
5,000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000-250,000
250,000-500,000
Over 500,000
Population Size Groups
Total Area - Dollars of investment necessary to attain the activated sludge level of BOD removal
Shaded Area - Dollars presently invested in sewage treatment facilities

FIGURE 5

TABLE III

ESTIMATED VOLUME OF INDUSTRIAL WASTES BEFORE TREATMENT, 1964[1/]

Industry	Wastewater Volume (Billion Gallons)	Process Water		
		Intake (Billion Gallons)	BOD_5 (Million Pounds)	Suspended Solids (Million Pounds)
Food and Kindred Products	690	260	4,300	6,600
Meat Products	99	52	640	640
Dairy Products	58	13	400	230
Canned and Frozen Food	87	51	1,200	600
Sugar Refining	220	110	1,400	5,000
All Other	220	43	670	110
Textile Mill Products	140	110	890	N. E.
Paper and Allied Products	1,900	1,300	5,900	3,000
Chemical and Allied Products	3,700	560	9,700	1,900
Petroleum and Coal	1,300	88	500	460
Rubber and Plastics	160	19	40	50
Primary Metals	4,300	1,000	480	4,700
Blast Furnaces and Steel Mills	3,600	870	160	4,300
All Other	740	130	320	430
Machinery	150	23	60	50
Electrical Machinery	91	28	70	20
Transportation Equipment	240	58	120	N. E.
All Other Manufacturing	450	190	390	930
All Manufacturing	13,100	3,700	22,000	18,000
For comparison: Sewered Population of U. S.	5,300[2/]		7,300[3/]	8,800[4/]

1/ Columns may not add, due to rounding

2/ 120,000,000 persons x 120 gallons x 365 days

3/ 120,000,000 persons x 1/6 pounds x 365 days

4/ 120,000,000 persons x 0.2 pounds x 365 days

Finally, the cost paid by the municipal user of sewage collection and treatment facilities was calculated in Reference 4 and is shown in Table IV.

Much of the effort in the R&D Program has been devoted to removing the last remaining traces of organics from water. This is certainly necessary for certain reuse applications. For pollution control, however, the need for extremely high removal or organics might not be needed for many years. This is shown in the simple analysis depicted in Figure 6. It was assumed that 85% removal from all municipal wastes in 1968 would be an adequate standard to protect the quality of the streams. As the population increases, removal efficiencies greater than 85% would be required to hold the pollutional load discharged fixed. The removal needed is shown in Figure 6 as a function of urban population. Notice that 90% removal would not be required until 1988 and 95% removal which might be effected with microscreening would not be needed until the population reaches 450 million.

A significant fraction of the R&D expenditure is for reuse applications. The anticipated expenditure for new construction and operating and maintenance can be roughly projected for reuse projects. It will be assumed here that no desalting processes will be necessary. For example, the estimated need for municipal water supply in four water resource regions of the Southwest Region of the United States is shown in Figure 7.

To use this data we must estimate the fraction of water supply need which is likely to be fulfilled by reuse of return flows. For example, we have assumed that one-half of the water needed in Southern Pacific and Western Gulf and all of the needs in Colorado and Rio Grande-Pecos

TABLE IV

TOTAL COST OF SEWAGE COLLECTION AND TREATMENT IN 1968
ON A CONTINUOUS CASH FLOW BASIS

1968 dollars/capita/year

Amortization Cost		
House Connection	$1.38	
Municipal Sewers	$8.64	
Interceptors and Outfalls	$2.46	
Treatment Plants	$2.83	
Total Amortization Cost	$15.31	
Current Expenses		
Municipal Sewer Maintenance		$0.86
Treatment Operation and Maintenance		$1.55
Customer Service and Accounting		$0.71
General and Administrative		$1.37
Total Current Expenses		$4.49
Total Cost of Municipal Collection and Treatment	$19.80	
Imputed Cost of Industrial Wastewater Treatment	$5.05	
Total	$24.85	

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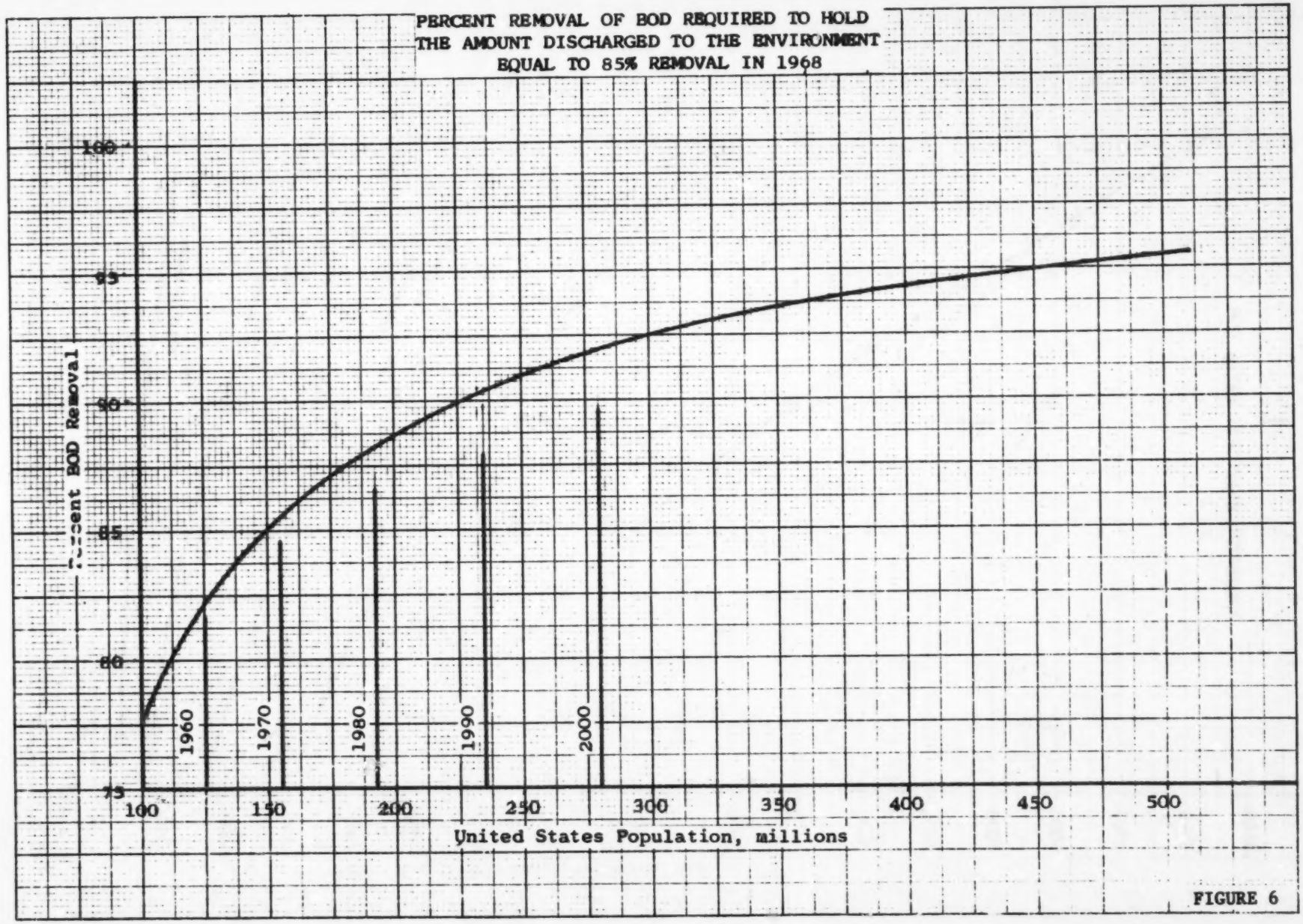


FIGURE 6

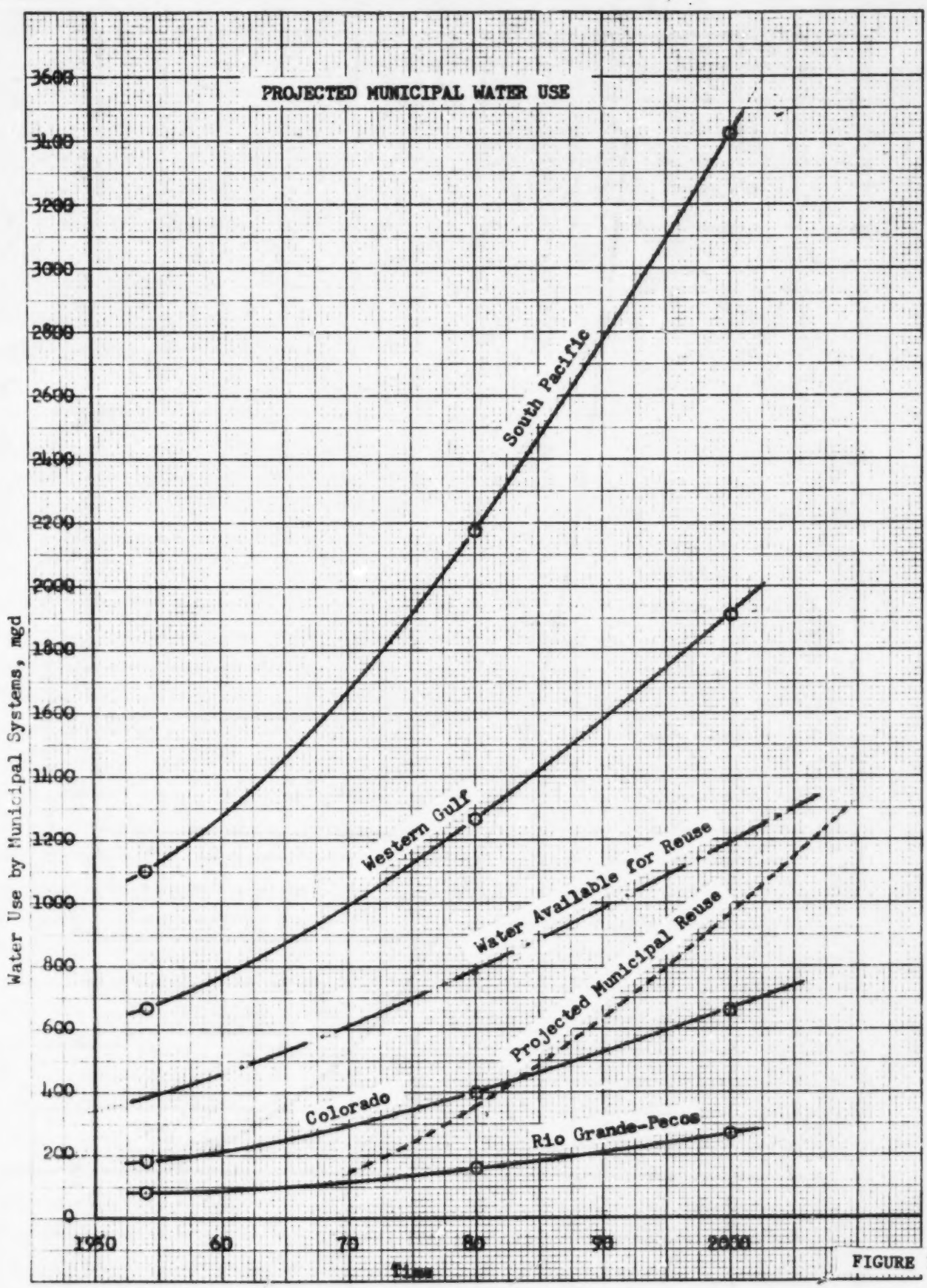

PROJECTED MUNICIPAL WATER USE
Water Use by Municipal Systems, mgd
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1950
60
70
80
90
2000
Time
South Pacific
Western Gulf
Water Available for Reuse
Projected Municipal Reuse
Colorado
Rio Grande-Pecos

FIGURE 7

might be augmented by reuse. We know that in these semi-arid areas of the country only about one-third of the water used is returned through the sewage treatment plant. The remainder is used consumptively for private and municipal watering. We can, therefore, estimate the total wastewater available for reuse as shown by the dashed line. Clearly, nothing approaching this amount of wastewater is now being reused. As time goes on, however, the pressures for reuse will increase and we can estimate that within 30 years an appreciable amount of the wastewater will be reused. This anticipated amount of reused water is also shown by a dashed line.

We can now convert this anticipated need line to construction and operating and maintenance cost. Once acceptable treatment methods are known, the goal of R&D reduces to finding ways of producing the quality of water required at a significantly lower cost. The total cost of treating wastewater for municipal reuse is about 20 cents/1000 gallons excluding salt removing processes. This is divided between amortization at about 7 cents/1000 gallons and operating and maintenance at 13 cents/1000 gallons. Since the number of reuse plants in existence is limited, we cannot assume that four percent of the plants will be replaced each year. Instead we have computed the cost of building the plants at $27/capita and have assumed that after 20 years replacements will be built. This is shown in Figure 8.

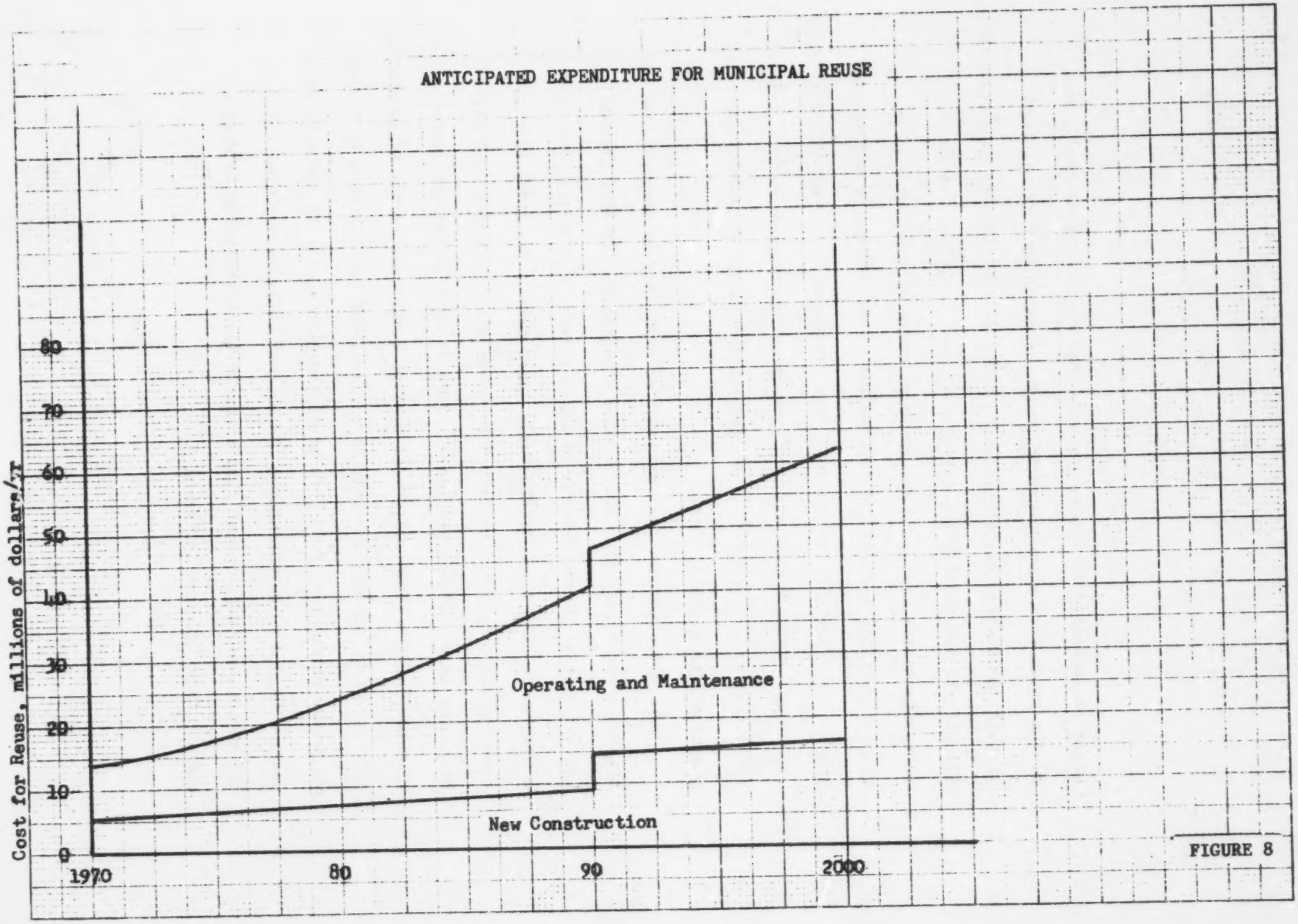

ANTICIPATED EXPENDITURE FOR MUNICIPAL REUSE
Cost for Reuse, millions of dollars/yr
80
70
60
50
40
30
20
10
0
1970
80
90
2000
Operating and Maintenance
New Construction

FIGURE 8

Notice that the magnitude of this anticipated expenditure is only about 1/20 or 1/30 of that expected for building and operating conventional plants. This fact would automatically place the funding of advanced wastewater treatment for reuse low on the priority list. This, however, would not necessarily limit the amount of spending because the cost of improving the design and operation of conventional plants might be relatively small. The present value (1970) of the cost stream represented by the upper curve in Figure 10 has been computed as $407.7 million dollars. If, as a result of the R&D Program, this cost can be reduced by 10%, the present value of the saving would be 40.8 million dollars. This is equivalent to about five years of R&D expenditure at the $9.7 million dollar/year level.

CURRENT RESEARCH AND DEVELOPMENT NEEDS

Wastewater treatment is concerned first, with removing dissolved and particulate pollutants from wastewater and second, with treatment and disposal of the organic and inorganic concentrates in some non-polluting way. The pollutants present in wastewater which must be removed to make the water suitable for reuse or discharge to surface waters are classified by the sub-category names used in the PPBS 1700 category. These are

1. Organic, suspended or dissolved, biodegradable or non-biodegradable
2. Nutrients, basically nitrogen and phosphorus
3. Pathogenic bacteria and virus
4. Heavy metals and toxic chemicals
5. Dissolved salts.

What follows is not meant to be an authoritative or comprehensive review of the current status of treatment or a complete enumeration of critical needs but only a response to questions raised in the memorandum from F. M. Middleton entitled, "Sensitivity Analysis in AWT Program" dated July 27, 1970.

Water quality standards adopted by the States for nine classes of surface water are very general and do not include specific effluent quality standards. In President Nixon's message to Congress of February 10, 1970[5] it was proposed that "State-Federal water quality standards be amended to impose precise effluent requirements on all industrial and municipal sources. These should be imposed on an expeditious timetable, with the limit for each based on a fair allocation of the total capacity of the waterway to absorb the user's particular kind of waste without becoming

polluted." Based on this we can look forward to the imposition of effluent quality standards.

Very little of the work on treatment is directed toward removal of heavy metals and pathogenic chemicals. More work in this area might be needed. If the concentration of coliforms and virus in an effluent are part of the effluent standard, this could become a critical need. The presence of ammonia, suspended solids and dissolved organics in secondary effluent make it extremely difficult to disinfect the water or, in the case of virus, to detect the presence of virus particles and thus test the effectiveness of the disinfection process.

The imposition of effluent standards on all industrial sources could place a great demand on treatment technology and on the FWQA R&D Program. The need to consider secondary or advanced treatment for industrial sources could become a new critical need.

In the same message President Nixon stated "Many plants have been poorly designed and inefficiently operated. Many plants have offered free treatment to local industries, then not treated their wastes sufficiently to prevent pollution." This statement presages one of the most important needs of the future. Methods are critically needed to assess the performance of existing treatment facilities in terms of the technically feasible capabilities of treatment processes, the character of the influent stream, and the operating and maintenance policies practiced at the plant. For example, the stochastic nature of process performance is not known, and is seldom studied. Many of the controversies which exist over design methods might be due to this serious omission. The effect of time varying parameters such as seasonal or diurnal variation of the

raw waste stream are largely unknown and little work is now underway, Simple graphical methods which the plant operator can use to determine if his plant is operating within the accepted standards for the installed equipment and structures are needed. State sponsored surveillance programs are needed to monitor the performance of all plants in the State. These kinds of programs will serve to check the validity of measurements made at individual plants and also to improve our knowledge of the capabilities of specific kinds of processes and equipment. Quality control techniques can be profitably applied to these kinds of problems. Staffing standards and well laid out maintenance programs are needed to support the State Water Pollution Control Programs.

The advantages of various kinds of control loops for plant automation must be evaluated and the results documented. Where a clear cost or performance advantage is demonstrated, use of the control loop should be promoted among design engineering firms.

There is now a critical need for technology which will assure the best treatment possible with any set of installed facilities and will promote reliability and fail-safe performance. Equipment modification to allow the equipment to be serviced or replaced without draining the tanks or bypassing the flow is needed. For example, the results of a questionnaire reported in Reference 6 showed that on the average, plants bypass 10% of the time.

Active participation of the design engineering firms in these problems of performance, reliability, and fail-safe operation might be encouraged by showing municipalities the advantages of writing turn-key contracts which include guarantees of plant performance and minimized operating and maintenance cost.

As mentioned above President Nixon's message stated that the amount of each pollutant removed should be based on a fair allocation of the total capacity of the water way to absorb the pollutant. Removal of nutrients must then be based on the need for nutrient removal. A study should be made to determine the magnitude of the nutrient removal problem. For example, the need for dissolved nitrogen removal appears to be on questional grounds. The need for phosphorus removal seems to be more firmly established but the magnitude of the need is not well known.

Adequate methods exist for removal of phosphorus but removal of nitrogen remains a problem. For example, a recent cost estimate made by Bechtel Corp. for a 300 mgd Blue Plains Plant, estimates the cost of nitrification as 5.48 cents/1000 gallons and the cost of denitrification as 5.64 cents/1000 gallons. The corresponding cost of the activated sludge process* was given as 3.62 cents/1000 gallons. Ammonia stripping towers can be used in the warmer climates but the process is still plagued by the scaling problem. In summary, there appears to be no reasonably economic solution for nitrogen removal and the character and magnitude of the need for nitrogen removal has not been established.

Recent cost estimates for the reverse osmosis process received from Aerojet General Corp. place the cost at 40-50 cents/1000 gallons. This is believed to be reasonable because the process can conceivably be used as a substitute for primary, secondary, and salt removing processes. The process is not practicable for this application at the present time.

* Pure Oxygen Modification

It also appears that the future need for desalting will be very limited. In water short semi-arid areas like the Southwest Region of the United States the return flow from a community averages only about one-third of the usage. This is because of private and municipal watering of plantings. A simple mass balance* for TDS around the community and treatment plant shows that when only one-half of the water is reused, the salt buildup is minimal. This relationship is depicted in Figure 9. Some work is underway now which will help to quantify the need for desalting but a more comprehensive study is needed.

The most fundamental need of all is a clearer understanding of the goals of the AWT R&D Program and a quantification and clarification of the needs in the proper time frame. A rational system for setting priorities will follow. Needs and priorities should be formalized and made available to the personnel of the AWT R&D Program as well as prospective contractors. Every effort should be made to minimize the amount of work now involved in handling proposals, contract negotiations, technical support for contracts, etc. More productive in-house activity is desperately needed.

*See Appendix II

FRACTION OF WASTEWATER WHICH CAN BE
REUSED BEFORE DEMINERALIZATION IS REQUIRED

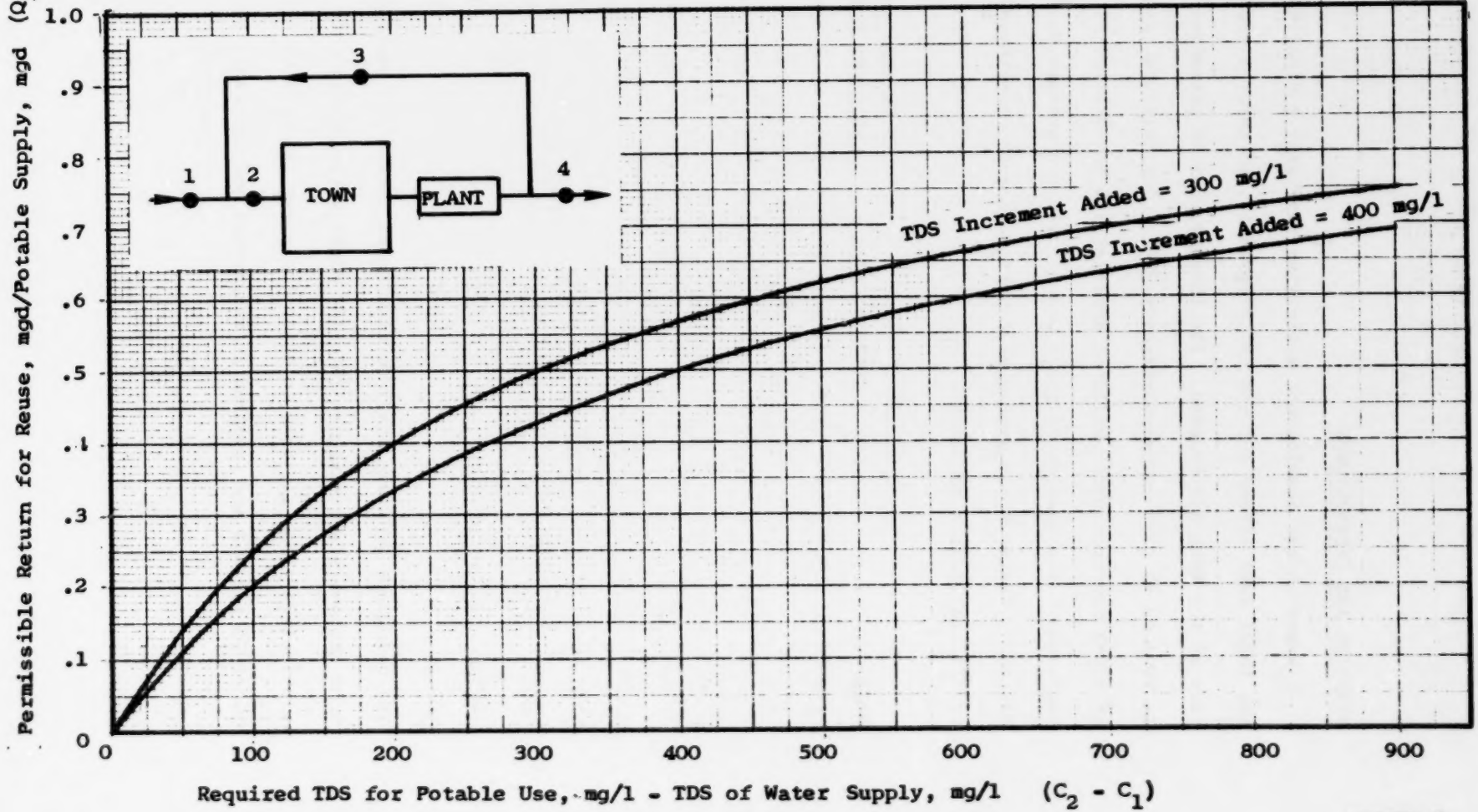


FIGURE 9

STAFFING AND EXPENDITURES

Research and development activities represent a significant part of the total FWQA effort and the AWT Program is, in turn, a significant part of the FWQA R&D Program. The total number of permanent positions in FWQA in FY 1970 was approximately 2416. The full-time equivalent of other non-permanent positions averaged 333 for a total of 2565 positions. The average GS grade was 9.7 and the average GS salary $12,652. Research and development personnel were distributed according to PPBS categories as follows:

PPBS	Persons Total	Persons in ADP, Lab. Service & General Fund
1100	56	3
1200	58	11
1300	29	5
1400	29	6
1500	23	4
1600	143	27
1700	125	20
1800	134	3
TOTAL	597	79

The permanent in-house staff at Cincinnati totals 121 employees. Thirty-nine employees are assigned to pilot plant activity and this number does not include those assigned to the pilot plant in the wing. A total of about 28 persons are involved in management and contracts and grant

administration. Twelve are PPBS sub-category coordinators. (See Appendix III) Twenty-four employees are located outside of the Cincinnati area. A breakdown according to organizational groups is shown in Table V.

A grand total of about 886 million dollars was expended by FWQA in FY 1970. Eight hundred million of this was expended as grants for construction of wastewater treatment facilities. The total for Pollution Control and Operations was, therefore, about 86 million dollars. An unobligated balance of about $11 million was carried over from FY 1969 for R&D. The total expended for R&D in FY 1970 was $48,509,033. This amount was distributed according to PPBS category as follows:

PPBS	Total Dollars/yr.	In-House Dollars/yr	$ In-House/$Total
1100	$11,745,950	$863,000	7.35%
1200	$6,746,000	$860,000	12.7 %
1300	$2,851,083	$588,000	20.6 %
1400	$2,777,000	$436,000	15.7 %
1500	$3,801,000	$467,000	12.3 %
1600	$8,827,000	$2,963,000	33.5 %
1700	$6,435,000	$2,775,000	43.0 %
1800	$5,326,000	$3,258,000	61.2 %
Total	$48,509,033	$12,210,000	Overall 25%

Expenditures excluding those for construction grants are about equally divided between Operations and R&D activities. PPBS sub-categories coordinated in Cincinnati are 1101, 1105, 1106, 1305, 1603, and all of

TABLE V

STAFFING TABLE FOR ADVANCED WASTE TREATMENT LABORATORY

Office of the Director

7 permanent
3 non-permanent

Contracts and Grants Activities

9 permanent
1 non-permanent

Treatment Optimization Research Program

6 permanent
1 non-permanent

Waste Identification and Analysis Activities

14 permanent

Biological Treatment Research Program

16 permanent
4 non-permanent

Physical and Chemical Treatment Research Program

13 permanent

Ultimate Disposal Research Program

11 permanent
1 non-permanent

Municipal Treatment Research Program

		Leb.	Pomona	Manassas	D.C. Pilot Plant
4	permanent	11	4	1	17
	non-permanent				3

Virus Identification and Removal Program

8 permanent

Totals 121 permanent
13 non-permanent

the 1700 series. The Cincinnati Advanced Waste Treatment Laboratory is involved in expending between 15-20% of the total R&D budget. About 23% of the in-house budget was spent in Cincinnati.

Now that we have some idea of the amount of expenditure for research and development we can make some estimate of what the payoff must be to justify the expenditure. The present value (1968) of the stream of expenditures for conventional municipal facilities shown in Figure 1 was computed, using 6% as the interest rate, as $14.92 billion dollars up to the year 2000. The yearly expenditure for R&D directly related to improving municipal treatment plants is about $20 million/year. Using annuity tables it can be shown that an expenditure of $20 million in each of ten years beginning in 1968 is equivalent to a present value of about $147 million or about 1% of the present value of the 32 year stream of expenditures. Thus, to justify the R&D Program spending $20 million each year for ten years we must show that a cost savings of at least 1% has been effected.

The anticipated expenditure for municipal reuse excluding demineralization is shown in Figure 8. The present value (1970) of this stream of expenditure was computed using interest at 6% as about $408 million dollars up to the year 2000. If we use the same ten year period, a one percent reduction in cost would justify the expenditure of about $600,000 per year. Similarly, a ten percent improvement in efficiency or reduction in cost would justify a $6 million expenditure. The potential for a significant payoff is clearly much larger in the area of conventional treatment than in process development for reuse. A similar analysis for desalting processes might cut the justified expenditures below the current spending rate.

It is doubtful that such an evaluation could be performed on each R&D project. It does seem reasonable, however, to attempt such an analysis for each PPBS sub-category in the 1700 series or even on each candidate wastewater treatment process.

INFLUENCE COEFFICIENTS

The potential cost saving or improvement in treatment efficiency which might be effected by a research project should be estimated before a decision of funding is made. To make the estimate, the change in total treatment cost must be estimated. Sometimes an influence coefficient is defined as the percentage change in the dependent variable (cost) resulting from a one percent change in the independent variable. In this report the term influence coefficient will be defined as the change in the independent variable necessary to effect a total treatment cost change of one cent per 1000 gallons of water treated. Care must be taken to stay within the valid limits of the design relationships used. In the following pages the actual change in cost resulting from a specified change in each independent variable will be given.

In order to avoid confusion, certain ground rules must be rigidly followed. First, the dependent and independent increments must be computed with respect to a specific, well defined, design point. The design point is defined by giving the values of all independent variables. Next, one and only one of the independent variables is incremented at a time. Finally, the magnitude of the change in the independent variable must be given with the associated change in total treatment cost.

TABLE VI

INFLUENCE COEFFICIENTS FOR COST INCREMENTS
CAUSED BY CHANGE IN DESIGN VARIABLES

CONVENTIONAL ACTIVATED SLUDGE WASTEWATER RENOVATION SYSTEM

Process Diagram is given in Figure 10

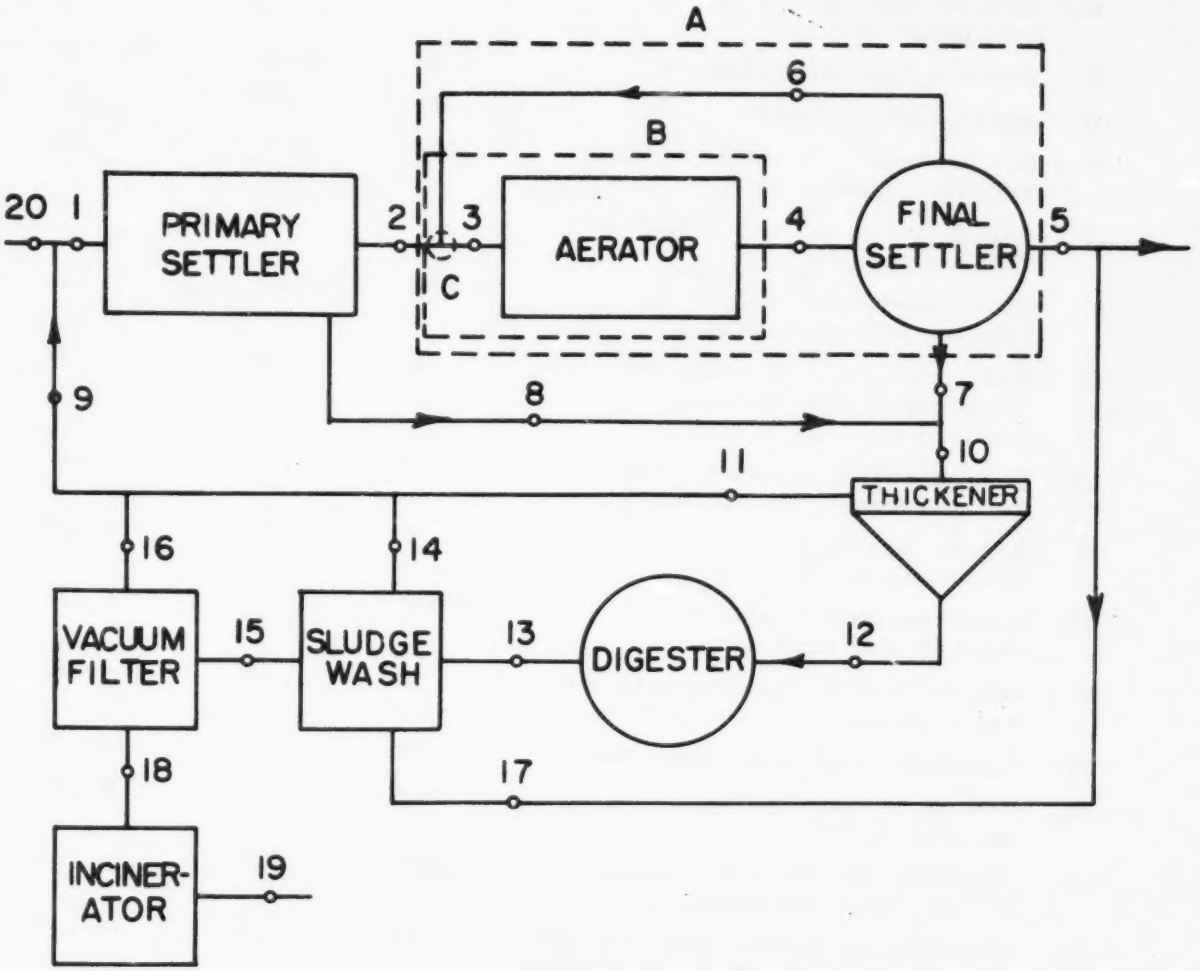
Design Point Total Treatment Cost = 10.90¢/1000 gallons

Influent Stream Characteristics:

Volume flow	10 mgd
Solid organic carbon	105 mg/l
Dissolved organic carbon	43 mg/l
Solid BOD	140 mg/l
Dissolved BOD	60 mg/l
Solid nonbiodegradable carbon	30 mg/l
Dissolved nonbiodegradable carbon	11 mg/l
Solid organic nitrogen	10 mg/l
Dissolved nitrogen	19 mg/l
Solid organic phosphorus	2 mg/l
Dissolved phosphorus	4 mg/l
Solid fixed matter	30 mg/l
Dissolved fixed matter	500 mg/l
Volatile suspended solids	225 mg/l
Total suspended solids	255 mg/l
Alkalinty	250 mg/l

Design Variable Changed	Initial Value	New Value	Cost Increment ¢/1000 gallons
1. Volume flow entering the system at station 20, mgd	10	20	-1.07
2. Total demand BOD concentration at station 5, mg/l	13	5	+4.62
3. Total concentration of solids in the aerator, mg/l mass	2000	1000	+1.91
4. Water temperature, degrees centigrade	20	10	+1.29
5. Ratio; SS_7/MLSS of the aerator	3	5	- .12
6. Efficiency of diffusers in aerator at zero dissolved oxygen and 20°C	.050	.025	+ .63
7. Concentration of dissolved oxygen in the aerator, mg/l oxygen	1	2	+ .07

Design Variable Changed	Initial Value	New Value	Cost Increment ¢/1000 gallons
8. Cost of electrical power, $/kilowatt-hour	.01	.02	+ .49
9. Construction cost index	1.25	1.40	+ .67
10. Amortization factor	.058	.062	+ .41
11. Design overflow rate for final settler, gpd/sq ft	2000	1000	+ .53
12. Solids recovery ratio for thickening, SS_{12}/SS_{10}	.95	.90	+ .07
13. Total suspended solids at station 12, mg/l mass	60000	50000	+ .40
14. Cost of ferric chloride for treating washed sludge, $/pound	.08	.10	+ .09
15. Design solids loading rate for thickener, lb/day/sq ft	9	5	+ .16
16. Solids recovery ratio for elutriation, SS_{15}/SS_{13}	.76	.90	- .04
17. Total suspended solids at station 15, mg/l mass	60000	50000	+ .11
18. Design solids loading rate for elutriation, lb/day/sq ft	9	18	- .11
19. Digester detention time, days	15	20	+ .23
20. Vacuum filter loading, gal./hr/sq ft	4.9	3.0	+ .27
21. Fraction of the time vacuum filters are operated	.238	.500	- .22
22. Fraction of solids entering the primary settler which is removed from the main stream 1 and sent to the thickener by stream 8	.5	.6	+ .34
23. Cost of chlorine, $/pound	.08	.05	- .20
24. Contractor's profit expressed as a fraction of the total capital cost	.10	.15	+ .21
25. Cost of contingencies and omissions expressed as a fraction of the total capital cost	.15	.20	+ .21
26. Dose of chlorine, mg/l	8	10	+ .13



CONVENTIONAL PROCESSES SYSTEM DIAGRAM

FIGURE 10

TABLE VII

INFLUENCE COEFFICIENTS FOR COST INCREMENTS
CAUSED BY CHANGE IN DESIGN VARIABLES

FLUIDIZED BED INCINERATION OF SEWAGE SLUDGE

Capital Investment Amortized at 6% for 20 years

Design Point Total Treatment Cost = .71175¢/1000 gallons

Design Variable Changed	Initial Value	New Value	Cost Increment ¢/1000 gallons
1. Volume flow, mgd	10	20	- .22618
2. Ambient air temperature surrounding the incinerator, ^{o}F	60	70	- .00103
3. Wall temperature of the incinerator, ^{o}F	200	250	+ .00520
4. Operating labor cost, $/year	5,000	7,000	+ .00342
5. Cost of the fuel, $/1,000,000 BTU	1.33	1.50	+ .00177
6. Fraction of time operated, hours operated/total hours	.25	.20	+ .04325
7. Cost of electrical power, $/kilowatt-hour	.03	.02	- .00638
8. Maintenance labor rate, $/hour	3	4	+ .00749
9. Maintenance service labor rate, $/hour	8	9	+ .00040
10. Percent H_2O in sludge	70	80	+1.180

SENSITIVITY FACTORS OF LAGOONING

Cost data were obtained from the report, "Cannery Waste Treatment, Utilization and Disposal" California State Water Resources Control Board Publication No. 39, 1968. The design point in all lagooning cases were taken as 1 mgd, 70% BOD removal and a land cost of $1000/acre. The total costs were amortized at 4 1/2% for 20 years.

The design point costs are given in Table VIII.

The authors distinguish the stabilization ponds primarily by depth as shown in Table IX.

The sensitivity factors are listed in Table X.

TABLE VIII

DESIGN POINT COSTS
FLOW = 1 mgd

Process	BOD Removal %	Area, Acres	Capital Cost Land	Capital Cost Other	O & M Cost/year	Total Costs ¢/1000 gallons
Aerated Lagoon	70	2.05	2050.	80019.	8324.	4.009
Anaerobic Lagoon	70	8.06	8060.	115966.	8475.	4.934
Facultative Pond	70	9.11	9110.	84598.	9132.	4.476
Aerobic Pond	70	13.44	13440.	43220.	5400.	2.673

TABLE IX

MAXIMUM DEPTHS OF LAGOONS

Pond	depth, feet
Aerobic	3
Facultative	6
Anaerobic	12

TABLE X

SENSITIVITY FACTORS

Variable to be Changed	Initial Value	Final Value	Aerated Lagoons	Anaerobic Lagoons	Facultative Ponds	Aerobic Ponds
Influent flow, mgd	1	2	-.314	-1.176	-1.254	-.825
BOD Removal, %	70	85	.913	------	1.358	1.467
BOD Removal, %	70	80	-----	1.565	------	-----
Cost of Land, $/Acre	1000	2000	.043	.170	.191	.282
Interest Rate (20 years), %	4.5	5.0	.076	.114	.085	.052

SENSITIVITY FACTORS FOR AERATION USING MECHANICAL AERATION DEVICES

The cost data were taken from the memorandum dated September 11, 1967, "Cost of Aeration of Secondary Effluents". The design point was taken as 10 mgd, 1¢/KWH and the DO level was raised from 1 ppm to 5 ppm. The total treatment cost in cents per 1000 gallons at the design point is 0.422.

Variable to Be Changed	Initial Value	Final Value	Cost Increment ¢/1000 gallons
flow, mgd	10	20	-.100
Effluent DO, ppm	5	6	+.167
Cost of electricity, ¢/KWH	1.0	2.0	+.040
Temperature, °C	20	30	+.312

SENSITIVITY FACTORS FOR THE TRICKLING FILTER PROCESS

The cost data used to calculate the sensitivity factors were obtained from the report "A Mathematical Model for a Trickling Filter" W69-2 and Figure 7 of the report "Cost of Conventional and Advanced Treatment of Wastewater". Two cases were considered, a 1 mgd and a 10 mgd plant. The trickling filter process includes the filter and the final settler. The entire plant costs consist of primary and final sedimentation, digestion, vacuum filtration, disinfection, incineration and the trickling filter. The results are listed below:

First Design Point

1 mgd, 5 mgd/acre, recycle = 2.0 and 85% BOD removed
Total treatment cost of entire plant = 15¢/1000 gallons
Total cost of trickling filter process only = 6.69¢/1000 gallons
Total cost is the amortized cost (4.5% for 20 years) plus the operating cost in units of cents per 1000 gallons

Second Design Point

10 mgd. 5 mgd/acre, recycle = 2.0 and 85% BOD removal
Total treatment cost of entire plant = 8.73¢/1000 gallons
Total cost of trickling filter process = 3.94¢/1000 gallons

The sensitivity factors are tabulated in Table XI. A negative cost increment indicates a decrease in cost in going from the initial value to the final value. A negative sensitivity factor reflects a decrease in cost whenever the variable in question is increased. Note that the depth is a function of the hydraulic loading. In other words deeper filters allow higher hydraulic loadings and consequently a reduction in cost per 1000 gallons treated. Also, if the recycle ratio is zero then the program neglects the costs of the entire recycle pumping station. This is a substantial decrease.

Figure 11 illustrates the dependence of the total cost of treatment for a full sized plant on the influent flow. Note the slight curvature. This is caused by the curvature of the digester cost curve.

TABLE XI

SENSITIVITY FACTORS

Design Variable Changed	Plant Size, Mgd	Initial Value	New Value	Cost Increment ¢/1000 gallons	Sensitivity Factor cost/ variable
Influent flow, mgd	1	1	2	-2.61	-2.61¢/mgd
	10	10	12	- .21	- .105¢/mgd
Percent BOD removed, %	1	85	80	-1.415	.283¢/%
	10	95	80	- .64	.128¢/%
Depth, ft	1	6	8.39	- .984	- .224¢/ft
	10	3.62	3.80	- .23	-1.27¢/ft
Recycle Ratio	1	2	1	- .301	.301¢
	1	1	0	- .934	.934¢
	10	2	1	- .10	.10¢
	10	1	0	- .65	.65¢
Hydraulic loading, mgd/acre	1	5	9	- .623	- .156¢/mgd/acre
	10	5	6	- .23	- .23¢/mgd/acre
Temperature, °C	10	20	16	.30	.075¢/°C
Cost of electricity, cents/KWH	10	1	1.5	.14	.28¢/¢/KWH
Overflow rate, gallons/sq ft/day	10	2000	1400	.21	.00035¢/gallons/sq ft/day

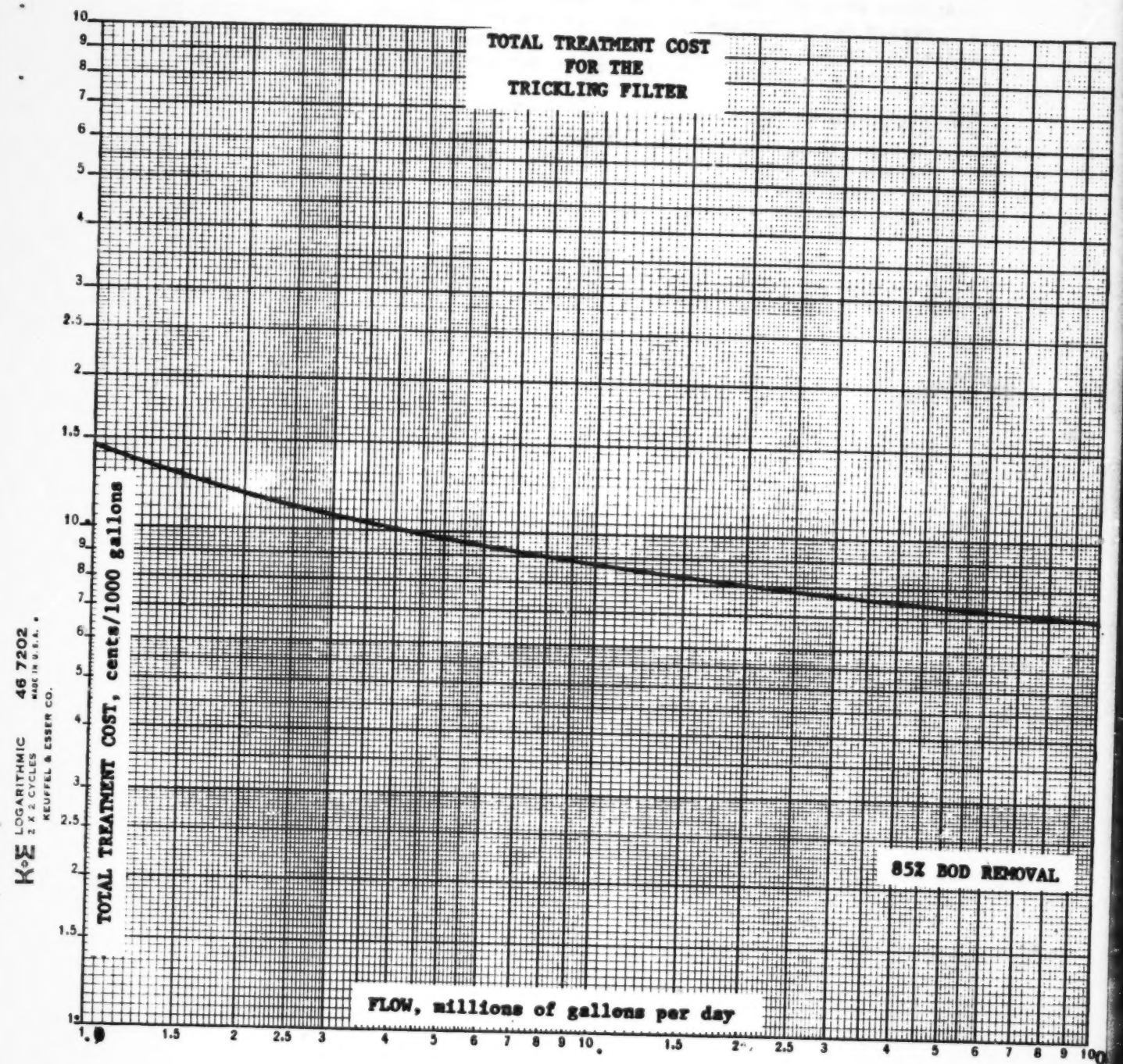

TOTAL TREATMENT COST
FOR THE
TRICKLING FILTER
TOTAL TREATMENT COST, cents/1000 gallons
FLOW, millions of gallons per day
85% BOD REMOVAL
K&E LOGARITHMIC 46 7202
2 X 2 CYCLES
KEUFFEL & ESSER CO.

FIGURE 11

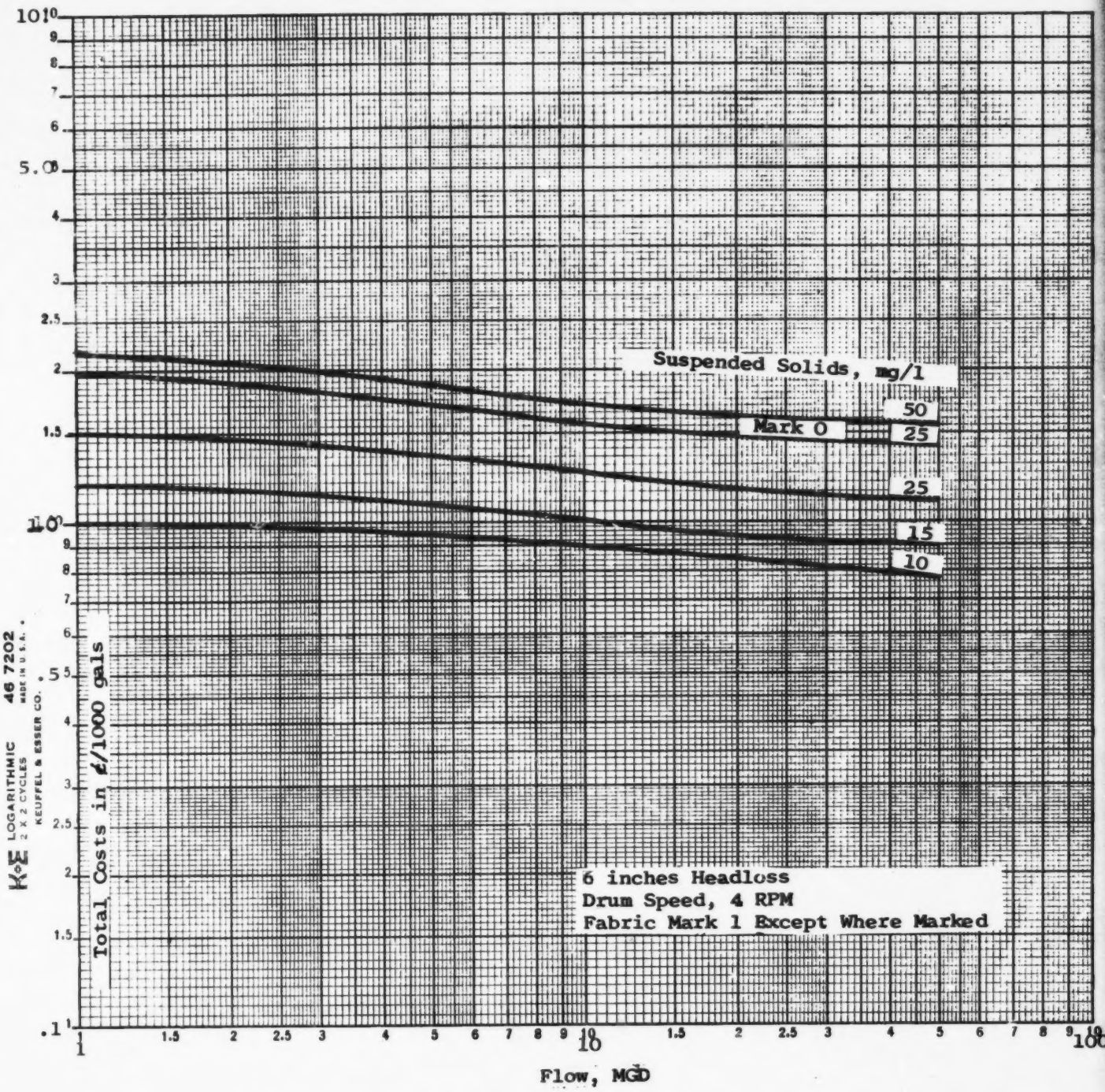
SENSITIVITY FACTORS FOR MICROSCREENING

Cost data were obtained from the report "Preliminary Design of Surface Filtration Units (Microscreening)" by Joseph F. Roesler. Figures 12 & 13 illustrating the dependence of cost on drum speed, flow, and suspended solids were also taken from the report and are enclosed in this memo.

The design point for sensitivity factors is

1 MGD, 25 mg/l suspended solids
4 RPM drum speed
6 inches headloss
Mark I fabric (Glenfield Kennedy Product)

The sensitivity factors are listed in Table XII. The sensitivity factor for the type of fabric is extremely crude. The only manufacturer having any fabric data is Glenfield Kennedy. Consequently, the type of weave is not considered.



THE COST OF HANDLING VARIOUS SOLID CONCENTRATIONS AT DIFFERENT FLOWS

THE COST OF VARYING DRUM SPEED

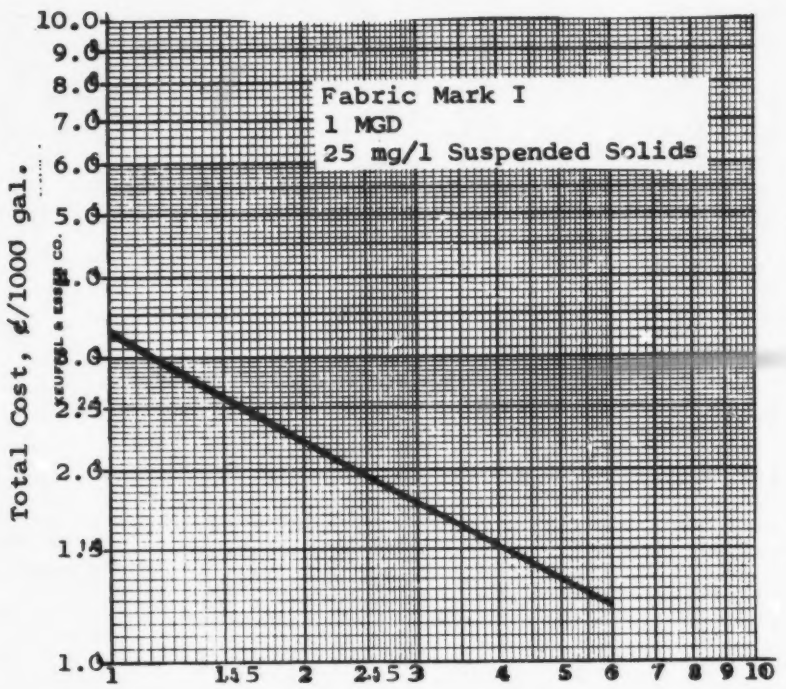


FIGURE 13

TABLE XII

INFLUENCE COEFFICIENTS FOR MICROSCREENING

Variable to be Changed	Initial Value	Final Value	Cost Increment ¢/1000 gallons	Sensitivity Factors cost/ variable
Influent flow, mgd	1	2	-.04	-.04¢/mgd
Influent suspended solids, mg/l	25	50	.65	.026¢/mg/l
Drum speed, rpm*	4	2	.72	-.36¢/RPM
Headloss, in. of H_2O	6	4	.12	-.06¢/in.
Type of Fabric				
Glenfield & Kennedy	Mark I	Mark 0		
Screen opening, microns	35	23	.47	.039¢/micron

* Solids removal efficiency increases with decreasing drum speed.

TABLE XIII

INFLUENCE COEFFICIENTS FOR COST INCREMENTS
CAUSED BY CHANGE IN DESIGN VARIABLES

TERTIARY TREATMENT BY LIME ADDITION

Single Clarifier with no recalcination provided

Capital Investment Amortized at 6% for 20 years

Design Point Total Treatment Cost = 3.757 ¢/1000 gallons

Influent Stream Characteristics:

Volume flow	10.00 mgd
Solid organic carbon	9.05 mg/l
Dissolved organic carbon	12.58 mg/l
Solid BOD	10.05 mg/l
Dissolved BOD	2.96 mg/l
Solid nonbiodegradable carbon	4.05 mg/l
Dissolved nonbiodegradable carbon	11.00 mg/l
Solid organic nitrogen	1.49 mg/l
Dissolved nitrogen	21.00 mg/l
Solid organic phosphorus	.09 mg/l
Dissolved phosphorus	5.42 mg/l
Solid fixed matter	3.17 mg/l
Dissolved fixed matter	500.00 mg/l
Volatile suspended solids	21.53 mg/l
Total suspended solids	24.70 mg/l
Alkalinity	265.47 mg/l
Calcium	50.00 mg/l
Magnesium	25.00 mg/l
Ammonia nitrogen	0.00 mg/l
Ortho-phosphate	0.00 mg/l
pH of influent stream	7.85 mg/l

Design Variable Changed	Initial Value	New Value	Cost Increment ¢/1000 gallons
1. Volume flow, mgd	10	20	-.237
2. Final pH	10	11	-.939*
3. Cost of lime, $/ton	20	15	-.449
4. Fraction of CaO in lime	.98	.97	+.018
5. Fraction of MgO in lime	.01	.15	-.378
6. Operating temperature, ^{o}C	25	27	-.014
7. Power cost, ¢/kilowatt-hour	3	2	-.026
8. Operator's salary, $/year	8,000	10,000	+.128
9. Cost of $FeSO_4$, $/ton	25	20	-.275

* No $FeSO_4$ coagulant is used when the pH is as high as 11. So the total treatment cost goes down.

TABLE XIV

INFLUENCE COEFFICIENTS FOR COST INCREMENTS
CAUSED BY CHANGE IN DESIGN VARIABLES

RECALCINATION OF LIME SLUDGE WITH FLUIDIZED BED REACTORS

Capital Investment Amortized at 6% for 20 years

Design Point Total Treatment Cost = 7.146¢/1000 gallons

The total treatment cost includes the cost of maintenance, operation, amortization, lime makeup and solid waste (ash) disposal with a recalciner, from the inlet of the dewatering device through the exhaust stack.

Design Variable Changed	Initial Value	New Value	Cost Increment ¢/1000 gallons
1. Volume flow, mgd	10.	20.	-.0536
2. Fuel cost per million BTU, $	1.20	1.50	+.5089
3. Electrical power cost, $/kilowatt-hour	.015	.010	-.1868
4. Cost of operating labor, $/man-hour	2.00	3.00	+.0149
5. Cost of maintenance labor rate, $/man-hour	2.50	3.50	+.00749
6. Cost of maintenance service rate, $/man-hour	4.00	5.00	+.0004
7. Disposal cost of solid wastes for removal from plant site, $/ton	5.00	6.00	+.2018
8. Fraction of lime lost in blow-down, lbs CaO lost/lb CaO recovered	.20	.25	+.4449
9. Sludge heat input, BTU/pound of dry solids	500.	600.	-.2034
10. Estimated operating life of recalciner, years	20.	25.	-.2039
11. Cost per ton of lime delivered to location, $/ton	20.	25.	+.3739
12. Pounds of CaO lost through stack/pound of CaO recovered	.01	.02	+.0889
13. Fraction of lime lost in dewatering process, lbs of CaO lost/lb of CaO recovered	.01	.02	+.0007
14. Fraction of volatile solids in sludge, lbs of VS/lb of dry sludge	.10	.15	-.2118

INFLUENCE COEFFICIENTS FOR CARBON ADSORPTION TREATMENT OF SECONDARY EFFLUENT

Cost data presented in "Appraisal of Granular Carbon Contacting", TWRC Report No. 11 were updated to July 1970 and trended to a nationwide average using the FWQA Cost Index. Amortization was calculated on the basis of 5% and 20 years. The "Base Case" of that report was chosen as the design point for these cost comparisons. Various design variable were then changed and the effects on treatment costs were calculated for each case. Only one variable was changed at a time.

The design bases for the base case are:

Influent Quality, COD	60 mg/l (70% dissolved)
Vessel System	2 stage, downflow
Carbon Bed Dimensions	Minimum depth to dia. ratio = 1
Effluent Quality, COD	9.5 mg/l (80% dissolved)
Velocity	7 gpm/sq ft
Base Case Total Treatment Cost	11.87¢/1000 gallons

Choosing the design velocity establishes the carbon bed surface area. Velocity together with contact time establish bed depth.

Variable Tested	Base Case Value	New Value	Cost Increment ¢/1000 gallons
Carbon Cost, ¢/pound	26	32.5	+ .53
Regeneration Loss, %	5	10	+ 1.13
Contact Time, minutes	50	25	- .84
Carbon Loading, lb COD/lb carbon	.522	.25	+ 1.41
Carbon Loading, lb COD/lb carbon	.522	.87	- .55
Plant Capacity, MGD	10	1	+25.04
Plant Capacity, MGD	10	100	- 4.03

SENSITIVITY FACTORS FOR AMMONIA STRIPPING BASED ON BLUE PLAINS DATA

The computer program for ammonia stripping was used to obtain sensitivity factors for ammonia stripping. The height of a transfer unit used was based on the data obtained from Blue Plains. Data for both crossflow and counterflow towers are given. In the case of the counterflow tower the gas to liquid loading ratio (GP/LP) was set at 3.0 because at lesser values the ammonia concentration fails to decrease when calculated through an increment. The design points are listed below:

	Crossflow	Counterflow
Cost of electricity, cents/KWH	.8	.8
Wet bulb temperature, °F	60	60
Influent flow, mgd	5	5
Percent NH_3 removed	90	90
GP/LP ratio	2	3
Height of transfer, ft	7.32	12.51
Total treatment cost, cents/1000 gallons	4.206	6.22

TABLE XV

INFLUENCE COEFFICIENTS FOR AMMONIA STRIPPING

Design Variable to be Changed	Initial Value	Final Value	Cost Increment ¢/1000 gallons
CROSSFLOW TOWERS			
Cost of electricity, cents/KWH	.8	2.	.961
Wet bulb, °F	60	32	3.343
	60	40	2.130
Influent flow, mgd	5	10	- .042
Percent NH_3 removed	90	80	-1.185
GP/LP ratio	2	3	+ .823
Height of transfer unit	7.32	5	- .743
COUNTERFLOW TOWERS			
Cost of electricity, cents/KWH	.8	2.0	.547
Influent flow, mgd	5	10	- .055
Percent NH_3 removed	90	80	-3.334
GP/LP ratio	3	4	-1.83
AHTU, height of transfer unit	12.51	5	-3.976

SENSITIVITY FOR THE ELECTRODIALYSIS PROCESS

The cost data used to calculate the sensitivity factors were obtained from the final report of Contract No. 14-12-410 (Mathematical Model of the Electrodialysis Process) by Process Research Inc. The costs appear to be optimistic but they are the most recent data available. The parameters requiring further definition are listed below:

GAMMA	ratio of the desired waste to product stream flow
RCM	cation membrane resistivity, ohm-sq cm
RAM	anion membrane resistivity, ohm-sq cm
TKNS	membrane spacer thickness, cm
TDEL	ratio of spacer thickness to mesh spacing
TDSI	total dissolved solids entering plant, mg/l
TDSO	total dissolved solids leaving the plant in the product stream, mg/l

The parameters defining the design point are listed below:

Influent flow	10 mgd
GAMMA	.083
Water temperature	70°F
Cost of electricity	1 cent/kwh
RCM	40 ohm-sq cm
RAM	40 ohm-sq cm
Current efficiency	.9
TKNS	.1 cm
TDEL	.1
TDSI	850 mg/l
TDSO	500 mg/l
Total treatment cost	8.67 cents/1000 gallons 5% @ 10 yr.

The sensitivity factors are listed in Table XVI.

TABLE XVI

INFLUENCE COEFFICIENTS FOR ELECTRODIALYSIS

Design Variable to be Changed	Initial Value	Final Value	Cost Increment ¢/1000 gallons
Influent flow, mgd	10	20	- .411
GAMMA	.083	.2	- .727
Water temperature, °F	70	60	.447
CKWH ¢/KWH	1.0	2.0	1.061
RCM	40	50	.041
RAM	40	50	.041
Current eff.	.9	.95	- .291
Spacer thickness, cm	.1	.2	3.931
Ratio of thickness	.1	.2	- .860
TDSI = 850 TDSO varies	500	400	2.370
TDSO = 500 TDSI varies	850	1000	2.308
Amortization factor 5% @ 20 years	.1295	.08024	-1.134
5% @ 25 years	.1295	.07095	-1.348

TABLE XVII

INFLUENCE COEFFICIENTS FOR REVERSE OSMOSIS

Design Variable Changed	Initial Value	Final Value	Cost Increment ¢/1000 gallons
Product water recovery, %	.87	.80	-3.65
Solids rejection, %	.85	.64	- .24
Influent flow, mgd	2.5	1.5	.51
Working pressure, psig	600.	750.	-8.28
Amortization factors			
5% @ 20 years	.1295	.08024	-3.74
5% @ 25 years	.1295	.07095	-4.45
TDS_f	800.	1000.	.35
Membrane life, years	2	1	16.

SENSITIVITY FACTORS FOR REVERSE OSMOSIS

Based on the work of Aerojet General and some in-house analysis, sensitivity factors were obtained for reverse osmosis. The basic equations used were obtained from Aerojet General's final report on Contract 14-12-184. The design point is tabulated below:

Design Point

Influent flow	2 mgd
Membrane coefficient	17.0 mg/(sq cm)(sec)(atm)
Initial flux	15.25 gal./(sq ft)(day)
Total dissolved solids in feed, TDS_f	800 mg/l
Working pressure	600 psig
Slope	.025
Solute rejection	.85
Amortization factor	.1295 - 5% @ 10 years
Treatment cost, ¢/1000 gallons	48.88

Some useful definitions are:

Product water recovery percent - the ratio of product water flow rate to feed water flow rate times 100;

Solids rejection percent - the ratio of the concentration of solids in the reject stream to the average concentration of solids in the entire plant times 100;

Working pressure - plant average effective pressure.

The sensitivity factors are listed in Table XVII.

WHAT NEEDS TO BE DONE

1. An organized program of planning and cost-benefit analysis should be established at AWTRL.

The goal of the program would be to allocate resources to maximize the impact of AWTRL on the national problem of water pollution control and reuse.

One of the first tasks should be to make an appraisal of each treatment process on which manpower and funds are being expended or for which research plans exist. This appraisal should include an estimate of the anticipated need, the opportunities for reducing cost or improving efficiency by means of FWQA sponsored research, and the importance of the process in meeting effluent quality standards or in treating wastewater for reuse. The appraisals should be made by someone not directly committed to studying the process; that is, by some totally objective person.

A priority ranking should be established based on the results of the appraisals and the ranking should be continuously modified as new information becomes available or as the needs of the Nation for water pollution control or reuse become better understood.

A recommended research program for the Advanced Waste Treatment Laboratory in Cincinnati should be submitted to Division of Process Research and Development at FWQA Headquarters for approval. This proposed program should be based on the appraisals and the priority ranking. A time frame for accomplishing specific improvements in process cost or effectiveness should be an essential part of the proposal. Progress reports should be keyed to the approved program and the importance of process improvements should be quantified in terms of their impact on the national water pollution control and reuse problem.

2. Particular attention should be given to recognizing critical treatment problems and initiating programs to find solutions as soon as possible. For example, disinfection of secondary effluent, removal of heavy metals or nitrogen removal.
3. More attention should be given to water pollution control in the industrial sector.
4. The needs of other groups within FWQA should be given every consideration in formulating the AWTRL research program. A closer interaction with groups such as Construction Grants and Engineering Branch, Basin Planning Branch, Systems Analysis and Economics Branch and other divisions of Research and Development should be encouraged. AWTRL should maintain a liaison with other governmental agencies such as OSW, HUD, EDA, FHA, and State water pollution control agencies.
5. Every effort should be made to anticipate the future needs for wastewater treatment and to have answers to problems when they are needed. One way of accomplishing this is to be familiar with all existing legislation, pending legislation, and plans of the Executive Branch. For example, the recently published First Annual Report of the Council on Environmental Quality[5] is an excellent source of philosphy and approach which will dominate the future course of the National Program for water pollution control and reuse.

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4. Smith, R. and Eilers, R. G., Cost to the Consumer of Collecting and Treating Wastewater in the United States, Unpublished FWQA report, July 1970.

5. The First Annual Report of the Council on Environmental Quality Transmitted to Congress, August 1970.

6. Federal Water Pollution Control Administration, U.S. Department of the Interior, Problems of Combined Sewer Facilities and Overflows, Water Pollution Control Research Series, WP-20-11, 1967.

APPENDIX I

According to accepted theory, the benefit associated with the execution of a particular R and D project is properly expressed as the present value of the benefit stream. The benefit stream is a series of dollar amounts which apply to specified time intervals in the future. The benefits are cost savings effected or improved treatment efficiency achieved expressed as dollar amounts.

The present value of the benefit stream is defined as follows:

$$B_o = \sum_{t=1}^{t=n} \frac{b_t}{(1+i)^t} \qquad (1)$$

Similarly, the present value of the stream of R and D costs incurred can be expressed as follows:

$$C_o = c_o - c_s/(1+i)^n + \sum_{t=1}^{t=n} \frac{c_t}{(1+i)^t} \qquad (2)$$

The <u>value</u> (V_o) of the research project can now be taken as the present value of the benefit stream minus the present value of the cost stream. The cost, of course, is the money and manpower resources spent on the R and D project. The yearly cost is assumed to occur at the end of each time period. The time period assumed in the above relationships is one year. If we wish to consider the costs or benefits as occurring <u>s</u> times a year, <u>n</u> in the formula is replaced with <u>sn</u> and <u>i</u> is replaced with <u>i/s</u>.

If the number of compounding periods in the year becomes very large corresponding to a continuous spending rate, equation (1) can be expressed as follows:

$$B_o = \sum_{t=1}^{t=n} \frac{b_t}{e^{it}} \qquad (3)$$

The total time period over which the benefits are expected to accrue must also be considered. Both the benefit and cost streams when (6% interest) discounted to time zero will approach a limit as the time increases. For example, the factor by which the benefit or cost associated with the 50'th year is divided is 18.42 while the factor for the 100'th year is 339.30. The most reasonable approach is to compute the present value of the cost and benefit streams over some period for which estimates of needs can be made, such as 30 years.

DEFINITIONS

B_o = present value of benefit stream, dollars

C_o = present value of cost stream

c_o = lump sum cost incurred at zero time

c_s = salvage value received at end of design period

t = time index, years

n = time index for last year in design period

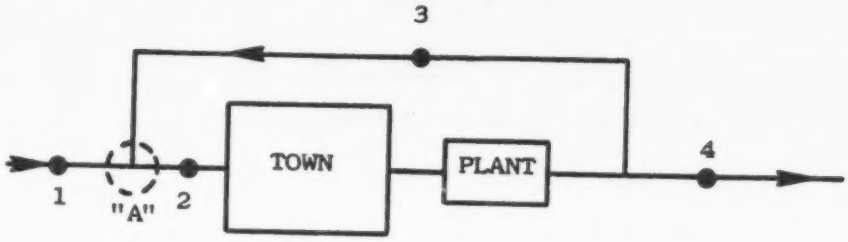
c_t = cost incurred in the t'th year, dollars

b = benefit realized in the t'th year, dollars

i = discount rate, percent/100

V_o = $B_o - C_o$ = present value of R and D project

APPENDIX II



To estimate the amount of water which can be recycled with no processes for removal of dissolved salts, a mass balance for TDS can be written around control volume "A" as follows:

$$Q_1C_1 + Q_3C_3 = Q_2C_2 \qquad (1)$$

We also know that municipal wastewater normally has a TDS concentration greater than the water supply by about 300-400 mg/l TDS. This is expressed as follows:

$$C_3 = C_2 + \Delta C \qquad (2)$$

By means of the mass balance for water around control volume "A", $Q_1 + Q_3 = Q_2$, we can eliminate Q_1 from equation (1). The following result is obtained:

$$\frac{Q_3}{Q_2} = \frac{C_2 - C_1}{C_3 - C_1} \qquad (3)$$

Using equation (2) to eliminate C_3 from equation (3) we obtain.

$$\frac{Q_3}{Q_2} = \frac{1}{1 + \Delta C/(C_2 - C_1)} \qquad (4)$$

DEFINITIONS

Q = volume flow, mgd
C = concentration of dissolved salts, mg/l
ΔC = increment of TDS added by use

APPENDIX III

MUNICIPAL POLLUTION CONTROL TECHNOLOGY

1101	Sewered Wastes	Cawley/Stenburg (Cincinnati)
1102	Combined Sewer Discharges	Rosenkranz
1103	Storm Sewer Discharges	Rosenkranz
1104	Non-Sewered Run-Off	Rosenkranz
1105	Non-Sewered Municipal Wastes	Cawley/Swanson (Cincinnati)
1106	Joint (Mun./Ind.) Wastes	Lacy/Swanson (Cincinnati)

INDUSTRIAL POLLUTION CONTROL TECHNOLOGY

1201	Metal and Metal Products	Lacy/Cincia (Edison)
1202	Chemicals and Allied Products	Lacy/Witherow (Ada)
1203	Power Production	Lacy/Rainwater (Corvallis)
1204	Paper and Allied Products	Lacy/Scott (Corvallis)
1205	Petroleum and Coal Products	Lacy/Myers (Ada)
1206	Food and Kindred Products	Lacy/Dostal (Corvallis)
1207	Machinery and Transportation Equipment	Lacy
1208	Stone, Clay and Glass Products	Lacy
1209	Textile Mill Products	Lacy/Hill (Athens)
1210	Lumber and Wood Products	Lacy/Boydston (Corvallis)
1211	Rubber and Plastic	Lacy
1212	Miscellaneous Industrial Sources	Lacy/Cincia (Edison)

AGRICULTURAL POLLUTION CONTROL TECHNOLOGY

1301	Forestry and Logging	Bernard/Hernandez (Corvallis)
1302	Rural Run-Off	Bernard/Bailey (Athens)
1303	Irrigation Return Flows	Bernard/Law (Ada)

AGRICULTURAL POLLUTION CONTROL TECHNOLOGY (Continued)

1304	Animal Feed Lots	Bernard/Scalf (Ada)
1305	Non-Sewered Rural Wastes	Bernard/Swanson (Cincinnati)

MINING POLLUTION CONTROL TECHNOLOGY

1401	Mine Drainage	Bernard/Hill (Cincinnati)
1402	Oil Production	Bernard/Keeley (Ada)
1403	Oil Shale	Bernard/Witherow (Ada)
1404	Other Mining Sources	Bernard
1405	Phosphate Mining	Bernard

OTHER SOURCES OF POLLUTION CONTROL TECHNOLOGY

1501	Recreational	Bernard
1502	Watercraft Wastes	Bernard/Lefcourt (Edison)
1503	Construction Projects	Bernard
1504	Impoundments	Bernard/Harlin (Ada)
1505	Salt Water Intrusion	Bernard/Keeley (Ada)
1506	Natural Pollution	Bernard
1507	Dredging	Bernard
1508	Oil Pollution	Bernard/Struzeski (Edison)
1509	Hazardous Material Spills	----------

WATER QUALITY CONTROL TECHNOLOGY

1601	Eutrophication	Joseph/Bartsch (Corvallis)
1602	Physical-Chemical Identification of Pollutants	Forziati/Nicholson (Athens)
1603	Biological Identification of Pollutants	Forziati/Berg (Cincinnati)

WATER QUALITY CONTROL TECHNOLOGY (Continued)

1604	Source of Pollutants	Forziati/Sanders (Athens)
1605	Fate of Pollutants in Surface Waters	Joseph/Sanders (Athens)
1606	Fate of Pollutants in Ground Waters	Joseph/Keeley (Ada)
1607	Fate of Pollutants in Coastal Waters	Joseph/Baumgartner (Corvallis)
1608	Water Quality Control	Cawley/Harlin (Ada)
1609	Water Resource Data	Shull
1610	Cold Climate Research	Cawley/Clark (Alaska)
1611	Water Resources Planning	----------
1613	Thermal Pollution	Gorchev/Rainwater (Corvallis)

WASTE TREATMENT AND ULTIMATE DISPOSAL TECHNOLOGY

1701	Dissolved Nutrient Removal	Cawley/Barth (Cincinnati)
1702	Dissolved Refractory Organics Removal	Cawley/Schwartz (Cincinnati)
1703	Suspended and Colloidal Solids Removal	Cawley/Hannah (Cincinnati)
1704	Dissolved Inorganics Removal	Cawley/Dobbs (Cincinnati)
1705	Dissolved Biodegradable Organics Removal	Cawley/Bunch (Cincinnati)
1706	Micoorganisms Removal	Cawley/Chambers (Cincinnati)
1707	Ultimate Disposal	Cawley/Dean (Cincinnati)
1708	Waste Water Renovation and Re-Use	Cawley/Middleton (Cincinnati)
1709	Waste Treatment Optimization	Cawley/Smith (Cincinnati)

WATER QUALITY REQUIREMENTS RESEARCH

1801	Municipal Uses	Allen/Herman (Duluth)
1802	Industrial Uses	Allen/Herman (Duluth)
1803	Agricultural Uses	Allen/Herman (Duluth)
1804	Recreational Uses	Allen/Herman (Duluth)
1805	Fish and Other Aquatic Life	Allen/Tarzwell (Narragansett) - Marine Waters Allen/Mount (Duluth) - Fresh Waters
1806	Marine Industrial Uses	Allen
1807	Marine Recreational Uses	Allen
1808	Marine Fish and Other Aquatic Life	----------